APPENDIX

Appendix A. Task 2 Technical Research Report

A62– Disaster Preparedness and Emergency Response Phase III
Task 2: Identification and Analysis of Technological Solutions to Enable Expanded Operations

August 20, 2024

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AI	Artificial Intelligence
AOPD	Air Operations Branch Director
API	Application Programming Interfaces
COP	Common Operating Picture
ERSI	Environmental Systems Research Institute, Inc.
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Agency
GA	Genetic Algorithm
GIS	Geographic Information Systems
GPS	Global Positioning System
GRC	Geospatial Resource Center
HVCR	Hierarchical Virtual Communication Ring
ICS	Incident Command System
LAANC	Low Altitude Authorization Notification Capabilities
LiDAR	Light Detection and Ranging
NASA	National Aeronautics and Space Administration
NOTAM	Notice to Air Missions
PDA	Preliminary Damage Assessment
RID	Remote Identification
RPIC	Remote Pilot in Command
SAR	Search And Rescue
SARCOP	Search And Rescue Common Operational Platform
SGI	Special Governmental Interest
TAK	Team Awareness Kit
TFR	Temporary Flight Restriction
UAH	University of Alabama Huntsville
UAS	Unmanned Aircraft System
WAAS	Wide Area Augmentation System

1 INTRODUCTION AND BACKGROUND

The following report is in response to Task 2 of the ASSURE Disaster Preparedness and Emergency Response Phase III project to research technological solutions of Unmanned Aircraft Systems (UAS) to enable expanded operations supporting disaster response and recovery missions. Phase III of this long-term program sponsored by the Federal Aviation Administration (FAA) focuses on coordination procedures, use cases, and technical solutions leading to more effective implementation of UAS by agencies and civilian partners responsible for disaster preparedness and emergency response. Task 2 of this program explores four key technology areas to support expand operational capabilities of UAS in complex environments. These technology areas organized in this report as the following subtasks:

1. Operations of Multiple UAS (Swarms),
2. Remote Identification,
3. Technology Enabling Situational Awareness, and
4. The Concept of an Automated "Air Boss."

Key questions Task 2 attempts to address include: "What is the role of automation and/or autonomy in UAS supporting disaster and emergency response and recovery missions?" What is are the implications of Remote Identification (RID) and airspace management in a disaster response environment?" "What services would a software solution need to enhance situational awareness for emergency responders?"

1.1 Task 2-1 Multi-Aircraft Operations (Swarms)

The University of Alabama Huntsville (UAH) performed a literature review to identify how UAS swarms can enhance public safety and disaster response. The coordinated behavior of UAS swarms provides unparalleled capabilities in covering large areas, adapting to dynamic environments, and maintaining robust communication, which are important factors in the success of disaster response and public safety operations.

1.1.1 Task Allocation and Coordination in UAS Swarms

The concept of task allocation within UAS swarms is a foundational aspect that enables these systems to effectively respond to complex and large-scale disasters. This division allows each UAS within the swarm to focus on a distinct area, thereby avoiding redundancy and ensuring thorough coverage. The k-means clustering algorithm is highlighted as a primary method for dividing a disaster area into smaller, manageable regions[1].The k-means algorithm operates by clustering geographic locations based on proximity, which allows for efficient resource distribution and minimizes the time required to search large areas. For example, during a post-earthquake scenario, UAS swarms can be deployed to rapidly survey the affected zones. Each UAS, guided by the k-means clustering algorithm, is assigned a specific sector to monitor. This targeted approach not only speeds up the search and rescue operations but also ensures that critical areas are covered more effectively than they would be with one or two singular UAS. Singular UAS would require more time to cover the same ground, potentially delaying the identification of survivors or hazards.

In the same study, the importance of coordination among UAS within the swarm is emphasized through the implementation of the Hierarchical Virtual Communication Ring (HVCR). This communication strategy is essential in disaster scenarios where traditional communication infrastructures may be compromised or overwhelmed. The HVCR framework organizes the swarm into smaller communication rings that maintain internal connectivity even if some UAS are isolated from the main network. This decentralized approach ensures continuous data sharing and supports real-time decision-making across the swarm [2]. Consider a flood response operation where communication networks are down. The HVCR allows UAS to continue gathering and transmitting critical data—such as water levels and evacuation route status—back to the command center. Unlike a single UAS, which might struggle to maintain a stable connection under these conditions, a swarm utilizing HVCR ensures that even if individual units lose connection temporarily, the overall operation remains unaffected. This resilience is particularly valuable in large-scale disaster management where the ability to maintain a steady flow of information can significantly impact the effectiveness of the response.

The application of "Genetic Algorithm planning" (GA) optimizes flight paths for each UAS, taking into account energy consumption, communication stability, and environmental factors such as obstacles and weather conditions. This method is especially useful in dynamic environments, such as those encountered during wildfire responses. The GA enables each UAS in the swarm to continuously adjust its path, ensuring that the entire area is monitored efficiently and that communication links within the swarm are maintained.

In comparison, a singular UAS operating without the benefits of swarm intelligence and GA-driven path planning would likely face challenges in maintaining efficient coverage, especially in environments where conditions are rapidly changing. A single UAS may need to make several passes to avoid obstacles, which not only consumes more energy but also slows down the overall response time. The swarm's ability to dynamically adjust and coordinate paths provides a clear operational advantage, particularly in scenarios where quick and comprehensive coverage is required.

1.1.2 Real-Time Data Collection and Decision-Making Support

UAS swarms significantly enhance real-time data collection and decision-making support in disaster scenarios by leveraging distributed sensor networks and advanced processing capabilities. The integration of various sensors—such as high-resolution cameras, Light Detection and Ranging (LiDAR), and thermal imaging—into each UAS is a key enabler for comprehensive data collection across large areas. Each UAS in the swarm contributes to a collective pool of data, which is processed and analyzed in real-time to inform decision-making.

For example, during a post-hurricane assessment, UAS swarms equipped with LiDAR can generate detailed maps of flooded areas, identifying both the extent of the flooding and structural damage. This data is critical for coordinating evacuation efforts and prioritizing rescue operations. The swarm's distributed data processing capabilities allow for quicker data analysis compared to a single UAS, which would need to relay data back to a central processing unit, potentially causing delays.

The importance of resilience in data processing and communication is emphasized within swarms [3]. Each UAS processes the data it collects locally before sharing it with the swarm, ensuring that the system can continue functioning even if individual UAS are lost or damaged. This decentralized approach not only speeds up data analysis but also adds a layer of reliability that is difficult to achieve with singular UAS.

For instance, in wildfire monitoring, the ability of each UAS in the swarm to independently analyze thermal data allows for real-time identification of hotspots and prediction of fire spread. This real-time analysis is crucial for directing firefighting efforts and ensuring the safety of personnel. A single UAS, limited by its processing capacity and the need to maintain continuous communication with a central command, would struggle to provide the same level of timely and accurate information.

Artificial Intelligence (AI)-driven algorithms enable UAS to refine their operations based on real-time data, improving their effectiveness over time[4]. In disaster scenarios, such as landslides, AI can help the swarm adapt its search patterns to focus on areas where survivors are most likely to be found, based on terrain analysis and other contextual factors.

Singular UAS would require manual intervention to adjust search patterns, potentially leading to slower response times and reduced operational efficiency. The ability of swarms to autonomously learn and adapt in real-time represents a significant advancement in disaster response technology, allowing for more effective and timely operations.

1.1.3 Public Safety Applications: Surveillance and Crowd Monitoring with Swarms

UAS swarms offer substantial benefits in public safety applications, particularly in surveillance and crowd monitoring during large-scale events or emergencies. The capability of a swarm to cover large areas simultaneously and provide real-time data makes it an invaluable tool for maintaining public order and ensuring safety. The application of swarms in monitoring public events is highlighted, where each UAS can be assigned to monitor different sectors of a large crowd. For instance, during a protest or concert, a UAS swarm can provide comprehensive surveillance by dividing the area into sectors and assigning each UAS to monitor a specific part. This approach allows law enforcement to receive real-time updates on crowd dynamics, enabling them to respond quickly to potential disturbances. In contrast, a single UAS would be limited in its coverage and might miss critical developments, especially in large and dense crowds.

The ability of swarms to monitor traffic flow and identify potential bottlenecks is also explored. During an evacuation, UAS swarms can track the movement of vehicles and pedestrians, providing real-time data on congestion points. This information can be relayed to emergency services, allowing them to adjust evacuation routes and allocate resources where they are most needed. A single UAS would struggle to provide the same level of coverage and real-time feedback, making it harder to coordinate large-scale evacuations effectively.

1.1.4 Role of Swarms in Disaster Recovery and Infrastructure Monitoring

UAS swarms are equally valuable in the recovery phase of disaster management, where they are used to survey damaged infrastructure, monitor repair efforts, and ensure the quick restoration of essential services. The role of UAS swarms in infrastructure inspections demonstrates their ability to provide detailed, real-time data on the condition of roads, bridges, and other critical structures.

For example, after a hurricane, a UAS swarm can be deployed to survey the damage to coastal infrastructure, such as seawalls, piers, and levees. By creating detailed maps of the affected areas, the swarm can help engineers assess the damage and determine the best course of action for repairs. Unlike singular UAS, which would be limited in their ability to cover all affected areas quickly, swarms provide comprehensive coverage, ensuring that all critical areas are assessed in a timely manner.

UAS swarms can also assess environmental damage and track the recovery of ecosystems after a disaster. For instance, after a wildfire, UAS in the swarm can monitor the regrowth of vegetation and assess the impact on wildlife habitats. This information is valuable for planning and implementing restoration efforts. Singular UAS would struggle to provide the same level of detailed, ongoing monitoring due to their limited capacity and slower operational speed.

Continuous monitoring by UAS swarms accelerates the recovery process by enabling the prompt identification and resolution of issues. In a post-disaster environment, where conditions can change rapidly, the ability to respond quickly to new information is important for ensuring the success of recovery efforts. For example, if a repaired road is found to be at risk of further damage due to ongoing flooding, the swarm can provide real-time data on the situation, allowing engineers to take preventive measures before the road is damaged again. This proactive approach to disaster recovery not only saves time and money but also helps to ensure the safety and well-being of affected communities.

1.2 Task 2-2 Remote Identification (RID)

UAH's research into the risks associated with unauthorized or unidentified UAS reveals significant safety concerns, particularly in restricted airspaces such as those surrounding airports, government buildings, and other critical infrastructure. The increasing prevalence of UAS in these areas raises substantial safety concerns, as evidenced by incidents like the collision between a hobbyist UAS and a Blackhawk helicopter in Staten Island, NY [5]. This collision, which resulted in considerable damage to the helicopter’s rotor blade, shows the severity of allowing unauthorized UAS to operate in sensitive airspaces. The incident not only endangered lives but also highlighted the disruption that unauthorized UAS can cause in critical operations, raising urgent concerns about airspace security.

The use of UAS by criminal organizations is an escalating issue. These groups are increasingly employing UAS for illegal activities, such as smuggling contraband into prisons or conducting covert surveillance on potential targets. This growing trend presents a complex challenge for law enforcement and public safety officials. The absence of a robust RID system makes it nearly impossible for authorities to track and intercept unauthorized UAS in real-time before they can cause significant harm. The capability to distinguish between lawful and unlawful UAS operations is crucial in urban environments where the density of UAS traffic complicates monitoring efforts.

There is an urgent need for advanced counter-UAS technologies to address these risks. More than 230 counter-UAS products are currently in development worldwide, incorporating technologies such as radar, active and passive optics, acoustics, and electromagnetic emissions. These technologies are essential for detecting, identifying, and neutralizing unauthorized UAS, particularly in complex urban settings where traditional methods may fail. Electromagnetic field detection, for example, has proven effective in tracking UAS that are not broadcasting their position—whether due to Global Positioning System (GPS) signal spoofing or intentional stealth operations. This capability is vital for countering sophisticated threats, including those posed by criminal organizations and potential terrorist activities.

The FAA's requirement for GPS location accuracy within 15 feet at the control station is vital for ensuring that authorities can pinpoint the exact location of a UAS operator during operations in sensitive areas, such as during disaster response or when UAS are deployed in restricted airspace [6]. However, the practical implementation of this requirement has sparked controversy within the industry. Organizations like ASTM have pointed out that achieving such precision with current commercial GPS technology is challenging. Typical GPS receivers can only achieve vertical accuracies between 42 to 108 feet under optimal conditions. These accuracies can be further compromised by environmental factors, such as tall buildings, dense urban infrastructure, or electromagnetic interference, raising serious concerns about the feasibility of compliance with the FAA's stringent accuracy requirements.

The FAA's detailed instructions for RID compliance show that ensuring all registered UAS operate within this legal framework is critical for maintaining public safety. The FAA outlines several compliance methods, including the use of standard RID UAS with built-in identification capabilities, RID broadcast modules that transmit the UAS's identification and location information, or flying within designated FAA-Recognized Identification Areas for UAS without RID equipment. These compliance methods are designed to offer flexibility for UAS operators while ensuring that all UAS in the National Airspace System can be tracked and identified by authorities, enhancing overall airspace security [7].

Leaders like Pierce Aerospace and Drone Tag are at the forefront of developing and implementing RID technologies. Pierce Aerospace is recognized for its advanced RID solutions, including specialized tags that can be affixed to UAS to broadcast identification information. These tags are particularly useful for retrofitting older UAS that do not have built-in RID capabilities. Drone Tag, on the other hand, has developed a range of products that integrate seamlessly with existing UAS systems, providing real-time identification and tracking capabilities. Both companies are playing a critical role in shaping the future of RID, ensuring that these technologies are accessible and effective for a wide range of users, from hobbyists to commercial operators and public safety agencies.

1.2.1 Disaster Response and UAS Integration

Research into disaster response shows the essential role that rapid UAS identification and classification play in ensuring effective and safe operations. During disaster scenarios, the airspace can become crowded with multiple UAS deployed by various agencies for tasks such as search and rescue, damage assessment, and the delivery of critical supplies. In these high-traffic environments, the ability to distinguish between authorized disaster response UAS and potential threats is crucial. The framework provided by the National Aeronautics and Space Administration's (NASA's) RID system is critical in this regard, allowing public safety officials to quickly identify and verify the legitimacy of UAS operations within disaster zones. This capability is particularly important when coordination among multiple agencies is required, as it helps prevent operational conflicts and ensures that all UAS activities are aligned with the overall disaster response strategy.

The effectiveness of NASA's RID system is evident in its multi-step identification process. This process includes the transmission of a unique vehicle identification number and the retrieval of comprehensive information from the Vehicle Registration and Model Database. Such a system is vital in ensuring that only authorized UAS are allowed to operate in sensitive areas, reducing the risk of interference or malicious activity. The ability to quickly access and verify this information is critical in disaster scenarios where unauthorized UAS could disrupt rescue operations or pose considerable risks to both first responders and civilians. The NASA RID system's capacity for near-instantaneous identification, with an average lookup time of just 1.2 seconds, significantly enhances the efficiency of disaster response operations.

To overcome the challenges associated with achieving the FAA's GPS accuracy requirements, the use of GPS receivers augmented with the Wide Area Augmentation System (WAAS) is recommended. WAAS offers vertical accuracy between 2.4 feet to 5 feet, significantly improving the feasibility of meeting the FAA's stringent 15-foot accuracy requirement. This level of precision is particularly advantageous in disaster response scenarios, where accurate location tracking is essential for coordinating multiple UAS operations. By enhancing the reliability of GPS signals, WAAS enables UAS to operate more effectively in challenging environments, such as urban canyons or areas with dense vegetation, where standard GPS signals may be less reliable.

1.2.2 Comparison with GPS Puck Technology

In comparing the capabilities of the GPS Puck with NASA's RID system, it was found that while the GPS Puck is useful for providing basic location data, it is insufficient for comprehensive public safety and disaster response operations. The GPS Puck does not offer the real-time information about the UAS's registration, operator, or intended flight path necessary for making informed decisions in high-stakes environments. For example, if an UAS equipped with a GPS Puck enters a no-fly zone near a disaster site, the GPS Puck would only provide basic location information without context, making it difficult for authorities to determine whether the UAS is authorized to be there. In contrast, NASA's RID system would allow authorities to quickly verify the UAS's authorization, identify the operator, and understand its mission, enabling a more accurate and timely response to potential threats.

The situational awareness provided by NASA's RID system is strengthened by its integration with existing UAS traffic management components, such as the Flight Information Management System and UAS Service Suppliers. This integration allows for a comprehensive understanding of the airspace, enabling authorities to track multiple UAS simultaneously, predict their trajectories, and assess potential risks in real-time. The GPS Puck, in comparison, is limited in scope and capability, making it less effective for managing complex airspace scenarios, especially during emergencies where rapid decision-making and real-time data are crucial.

The FAA's recommendation to use WAAS for GPS augmentation offers significant advantages in disaster response operations. The improved accuracy provided by WAAS ensures that UAS operate within their designated areas, reducing the risk of interference with other operations and allowing for the quick identification and management of unauthorized UAS. This enhanced precision is critical for ensuring that UAS contribute positively to disaster response efforts, rather than becoming an additional challenge for emergency responders.

1.3 Task 2-3 Situational Awareness Tools

Disaster and emergency response involves a wide range of individuals, teams, and depending on the scale multiple agencies to provide relief efforts. The Incident Command System (ICS) is a management structure framework designed for domestic incident response and integration of all necessary components for emergency management [8]. ICS incorporates six major functions:

- Command,
- Operations,
- Planning,
- Logistics,
- Intelligence and Investigations, and
- Finance and Administration.

Situational awareness and information sharing is an extremely important task in emergency management regardless of the scale of the incident. When multiple teams are mobilized for both ground and airborne response activities, the incident zone can quickly become a chaotic environment. ICS command staff and subsequent operations branch directors require accurate information to properly allocate resources, assigned personnel, and make informed decisions. Safety of response teams, deconfliction of response assets, and reduction of duplicated efforts are all concerns that effective situational awareness helps to solve.

There are several functions and capabilities that an effective situational awareness tool should provide to fill this operational niche. Data integration, communications, and risk reduction are the general functions but are further broken down into more defined technical capabilities, as shown in Table 1.

Table 1. Functions and Technical Descriptions.

Function	Technical Description
Operations Data	Ability to import and export a variety of geospatial and remote sensing data. This includes landscape data, elevation/terrain, and meteorological (current conditions and forecasts). Other valuable layers include the disaster zone extent, search areas, airspace and flight restrictions, and the location of the Base of Operations or other staging areas involved in response efforts.
Field Data	Integrate actionable data products as they become available to ICS command, planning, operations, and intelligence. This may include activity reports, cursor on target of mobilized units, UAS imagery, and ground photos derived from units in the field. The ability to export situational awareness maps to share with ICS and mobilized teams (digitally or hardcopy).
End User Functions	Consistency across multiple platforms, such as computers, tablets, and smart phones, and a means to allocate access for multiple users is an important function for data sharing across all necessary parties. This includes the ability to share access but also limit access based on bandwidth availability and need to know status.
Maintenance and Scalability	Technical maintenance of situational awareness tools and the ability to scale the tools as the incident scale changes, both an increase and decrease of demand, must be relatively seamless to avoid data and communication gaps.

Geographic Information Systems (GIS) areas the backbone of all situational awareness tools used in disaster and emergency response. By aggregating as much data as possible, or as necessary, to have a comprehensive understanding of the current conditions and expectations for response efforts, the ICS is able function within a "Common Operating Picture" (COP). There are several situational awareness tools in use by public safety to address these needs which are described in the following sections. All share a common foundation of integrating various GIS layers and datasets to provide a COP for disaster and emergency response efforts indicated previously.

1.3.1 Search and Rescue Common Operational Platform (SARCOP)

Search and Rescue Common Operational Platform (SARCOP) is an interagency platform developed and maintain by the National Search and Rescue Geospatial Coordination Group which was a created in partnership with the Department of Homeland Security Science and Technology Directorate and the Federal Emergency Management Agency (FEMA) Response Geospatial Office in following the 2020 Hurricane Season [9]. SARCOP aggregates a series of mobile applications, web map services, and geospatial analytics into a single web-based COP platform for assist in Search And Rescue (SAR) operations. While SARCOP is not advertised as a "Preliminary Damage Assessment tool" (PDA), it has become the standard platform for urban search and rescue teams across the country to map damage observations and collect valuable data points that are ultimately shared with Joint PDA Teams for damage assessment requirements in large scale, federal emergency response efforts. SARCOP also maintains a sandbox environment where users can conduct exercises within the same COP environment used in disaster response.

SARCOP uses Environmental Systems Research Institute, Inc. (ESRI) GIS tools, web services, and analytical capabilities as the foundational mapping software. ESRI was founded in 1969 to support geographic science and analytics for data management and environmental problem-solving and has since become an international standard for geospatial intelligence and mapping software [10]. Using field mapping toolkits, dashboard presentation platforms, and web-based analytics from ESRI, SARCOP is used from the individual first responder to the emergency operations center to maintain current intelligence of the disaster response efforts. Sharing information such as search areas, known hazards, points of interest, task assignments, and live imagery or data products, SARCOP has proven an extremely valuable situational awareness tool to help improve response activities and survivor outcomes. Data from the SARCOP and the after-action review reports produced by the platform offer local, state, and federal agencies with accountability metrics to verify SAR areas of interest have been surveyed for damage and victims. Specific ESRI tools employed by SARCOP include Quick Capture and Field Maps which are mobile applications to designed to streamline the collection of field data in real-time [11]. Custom GIS applications that function across multiple user-friendly platforms aid in the situational awareness mission by identifying and locating hazards, initial damage assessment of structure, and assigning tasks to first responders. This information is also geolocated and directly added as a GIS layer with supplemental information about the risk or mission status to SARCOP.

The FEMA Geospatial Resource Center (GRC) also uses ESRI as the backbone for data sharing and visualization during federal incident response [12]. The GRC provides a "living atlas" of US Structures, a databased inventorying all structures larger than 450 square feet for use in flooding incidents [13]. The GRC also maintains a curated data catalog of over 600 layers and historic incident responses by FEMA for use by local and state emergency management agencies as well as other public safety agencies performing disaster and emergency response activities. This combination of available data and powerful COP platforms is rapidly becoming the standard for situational awareness and more effective emergency response activities in the US.

1.3.2 Team Awareness Kit

The Android team Awareness Kit, or Team Awareness Kit (TAK), was initially developed by the Air Force Research Laboratory for military applications. TAK is a "government off the shelf" software application for geospatial mapping and communications using the Android operating system [14]. TAK is made available by the US Government at no charge to users with both TAK-based and Windows-based server configuration capabilities.

For public safety, TAK provides a situational awareness platform with variety of features, plugins, and tools ranging from mapping capabilities, cursor on target monitoring, two-way communication, image overlaying, navigation (overland orienteering, ranging, bearing, and distance measurement), and is compatible with most GIS data formats [15]. With a powerful software developer kit, users can create new tools or compile existing features into customized toolkits for a mission-specific COP. TAK also provides a means to integrate Application Programming Interfaces (API) with any Android or Windows compatible software. With this capability, developers have built APIs to operate UAS and receive data streams using on one application, making the flexibility to perform most functions of a team, from operations to data sharing to analytics possible in a single environment. When connected to wireless networks or mobile ad hoc networks, TAK users can manipulate these features in real-time making adding to the robustness of TAK as a situational awareness tool.

1.3.3 CALTOPO/SARTOPO

CALTOPO started as a pilot project from by a California first responder to aggregate digital maps and other GIS layers to aid in SAR mission [16]. CALTOPO is available to general public as a desktop and mobile application for planning and mapping of backcountry hiking, skiing, and camping. The base application provides elevation layers, snow depth estimates, daily satellite imagery, water body levels, meteorological forecasts, and public land GIS layers [17]. CALTOPO later created a first responder-oriented platform known as SARTOPO as a situational awareness tool to help organize and coordinate disaster and emergency response efforts through real-time mapping. With a collaborative workspace sharable to multiple users and across multiple platforms, SARTOPO offers live tracking and locators of teams in the field, in incident command posts, and in the emergency operations center with the capability to monitor response progress and mark points of interest, such as hazards, structures, or staging areas. Data integration capabilities for most GIS data formats are augmented by built-in mapping tools to draw, update, and analyze data in real-time to push to the SARTOPO environment. SARTOPO offers first responder only features to aid in SAR missions as well including SMS locators which provide valuable information about cell phone pings and mutual aid incident features when response efforts require multiagency coordination groups for larger scale emergency management.

1.4 Task 2-4 Automated Air Boss

Air Operations during disaster and emergency response are performed within the Operations Section of the ICS. The Air Operations Branch Director (AOBD) is responsible for supervising and configuring the Air Operations Branch as necessary to maintain full operational control over incident related air support and assets, both manned and uncrewed resources [18]. Additionally, the AOBD is oversees the airspace safety and deconfliction by coordinating within a Temporary Flight Restriction (TFR) and flight routes where state and federal agencies need air resources. The Remote Pilot in Command (RPIC) is the field operator responsible for the overall operation and safety of a UAS team and is responsible for communicating all mission and flight plans to the

AOBD [19]. Depending on the scale of a disaster, the airspace where air resources are operating can rapidly become congested.

AOBD operational qualifications require competency in conducting operations and ensuring completion of assigned tasks. This includes setting priorities, developing and implementing plans, coordinating with appropriate personnel and stakeholders, evaluating information on risk and incident requirements to modify plans, completing required documentation, maintaining full situational awareness of all aviation operations, supervising Air Support Groups, and managing aviation support facilities and aircrew personnel, amongst many other duties and responsibilities within the ICS [20]. Reviewing and approving all flight requests to accomplish incident response objectives, to include the verification that public safety UAS operators and civil partners have the appropriate clearance to operate within a TFR by way of the Special Governmental Interest (SGI) process, is an important task to ensure safe and efficient operations are conducted. It is not uncommon for RPICs to operate under the FAA 14 CFR Part 107 rules and regulations in a disaster area using other means to receive airspace authorizations. These include submitting Low Altitude Authorization Notification Capabilities (LAANC) approvals from participating airports. The AOBD is also responsible for coordinating with the FAA to restrict airspace over parts of the operational area as necessary and request appropriate Notice to Air Missions (NOTAM). Monitoring aircraft launch and recovery schedules, landing areas, available flight times, deconfliction of air resources, reduction of duplicated efforts by aircrew, and coordinating all of the above with weather hazards involves significant attention to situational awareness tools and changing incident objectives.

The concept of an Automated Air Boss is to reduce the various responsibilities of an AOBD on certain aspects of air operations coordination by identifying opportunities for automation. With developments in situational awareness tools and AI using large language models to generate text requests, there is a potential niche area for automation in the air operations decision making tree to accommodate for an increased demand of manned and uncrewed air resource requests. For instance, an Automated Air Boss tool may incorporate aircraft and team tracking with GIS layers depicting search areas to assign tasks to teams based on proximity and capabilities, such as thermal infrared sensors for SAR or fixed wing UAS for damage assessment mapping. By incorporating the concepts of RID and Automatic Dependent Surveillance-Broadcast, an Automated Air Boss tool may support deconfliction of manned and uncrewed assets by limiting altitudes, search areas, or flight scheduling. A potentially powerful function of an Automated Air Boss may include the ability to generate and submit SGI or LAANC requests on behalf of an operator for more rapid deployment of life saving missions. The same function may support more rapid standing up and closing NOTAMs in an operational area without the need for direct interaction by the AOBD or operators. With situational awareness tools monitoring weather activity in the operational area with active air operations, an Automated Air Boss may notify the potential risk to field operators and pilots through communication channels reserved for coordination. Proper planning and establishment of templates, predetermined decision-making criteria, order of operations for certain actions for an Automated Air Boss tool would require considerable development before deployment. For instance, a tool submitting airspace authorization requests on behalf of an RPIC would need to know the information and format of the request required by FAA centers responsible for reviewing and approving airspace authorization but the beneficial implications to reduce human intervention in menial tasks in order to safely deploy air resources during an incident and support safety monitoring in an operational area are considerable. Safety of air resources, aircrew personnel, and victims in the operational area is the top priority of AOBD followed very closely by accomplishing assigned disaster response tasks.

2 CONCLUSION

Agencies responsible for disaster response and emergency management are faced with the daunting challenge to balance safe operations with efficiently accomplishing life saving tasks. UAS technology has offered a wide range of benefits to first responders while at the same time adding a new tool to manage and maintain proficiency in. The four technology areas addressed in this report have identified of opportunities and challenges for further enabling the effective implementation of UAS in disaster response. The processes of autonomous systems introduce areas to expand operational capabilities and impact, such as with swarm technology, and in reducing human intervention to aggregate data for informed decision making, such as with the concept of an automated "Air Boss." With so many response activities taking place simultaneously during an emergency response, the requirement to maintain a COP across all incident response teams is a challenge in and of itself. This challenge not only involves collecting the right information for informed decision making but also presenting that data in a comprehensible way. Integrating universal knowledge that is expected by incident response teams in situational awareness platforms is addressing this issue by leaders in the geospatial and emergency management fields. Several of the most widely used situational awareness tools are presented in this report as well as some of the universal services that effective solutions should provide. Emergency management and the legacy process of disaster response follow very strict hierarchies through NIMS and ICS that every public safety agency, from local teams to nation-wide mobilizations, must adhere to. It is in accordance with this hierarchy that the development of new technical solutions must also integrate into to become an effective technology enabling expanded, more complex operations of UAS in disaster preparedness and emergency response.

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Appendix B. Task 3 Technical Research Report

ASSURE A62 – Disaster Preparedness and Emergency Response Phase III

Task 3 – Identification and Analysis of Additional Use Cases and Operational Characteristics

August 26, 2024

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16. Abstract

The objective of Task 3 in the FAA's research initiative focuses on identifying and analyzing additional use cases and operational characteristics of Unmanned Aircraft Systems (UAS) in disaster and emergency response and recovery missions. The research thoroughly examines various scenarios where UAS can be effectively utilized, extending to international contexts. It seeks to address critical questions regarding the deployment of UAS for disaster mitigation, situational awareness, and future health pandemic responses. The study also evaluates the suitability of different UAS platforms for specific mission types, the operational characteristics necessary for multi-UAS operations, and the lessons learned from past demonstrations. Furthermore, it explores scenarios where UAS may not be optimal, identifying instances where manned aircraft might be more efficient.

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TABLE OF ACRONYMS

AAIB	Air Accidents Investigation Board
AI	Artificial Intelligence
AED	Automated External Defibrillators
ASSURE	Alliance for System Safety of UAS through Research Excellence
ATC	Air Traffic Control
ATON	Aids To Navigation
BS	Base Station
BVLOS	Beyond Visual Line-Of-Sight
CONOPS	Concept of Operations
COP	Common Operating Picture
DEM	Digital Elevation Model
DLI	Divert Land Immediately
D-NET	Disaster Relief Aircraft Information Sharing Network
FAA	Federal Aviation Administration
FLIR	Forward-Looking Infrared
GCS	Ground Control Station
GPS	Global Positioning System
IoT	Internet of Things
IR	Infrared
JAXA	Japan Aerospace Exploration Agency
LIDAR	Light Detection and Ranging
LOS	Line of Sight
LUAS	Large UAS
NAS	National Air Space
NASA	National Air and Space Administration
NOTAM	Notice to Airmen
QR	Quick Response
RGB	Red Green Blue
RPIC	Remote Pilot in Command
RTB	Return to Base
RTL	Return to Land
SGI	Special Governmental Interest
sUAS	Small Unmanned Aircraft System
TAK	Tactical Assault Kit
TFR	Temporary Flight Restriction
UA	Unmanned Aircraft
UAS	Unmanned Aircraft System
UE	User Equipment
UTM	Unmanned Traffic Management
UV	Ultra-Violet
VLOS	Visual Line-of-Sight
VO	Visual Observer
VTOL	Vertical Take-Off and Landing

EXECUTIVE SUMMARY

The objective of Task 3 in the Federal Aviation Administration's (FAA) research initiative focuses on identifying and analyzing additional use cases and operational characteristics of Unmanned Aircraft Systems (UAS) in disaster and emergency response and recovery missions. The research thoroughly examines various scenarios where UAS can be effectively utilized, extending to international contexts. It seeks to address critical questions regarding the deployment of UAS for disaster mitigation, situational awareness, and future health pandemic responses. The study also evaluates the suitability of different UAS platforms for specific mission types, the operational characteristics necessary for multi-UAS operations, and the lessons learned from past demonstrations. Furthermore, it explores scenarios where UAS may not be optimal, identifying instances where manned aircraft might be more efficient.

Research for this task provided valuable insights into the risks and safety mitigations associated with UAS deployment in diverse disaster and emergency contexts. This report offers a comprehensive analysis, answering the FAA's research questions, identifying critical gaps, and highlighting essential focus areas for ongoing research. The following provides a summary of the research findings.

Findings for this task identified 57 new use cases for UAS in disaster response and recovery. These use cases represent areas where additional exploration and expansion of UAS deployment would be beneficial. Additional findings identified key qualifiers for multi-UAS operations for disaster response, highlighting the importance of communication, shared data, and a Common Operating Picture (COP). These elements ensure communication and data transparency and help maintain traffic separation. This task also identified UAS use cases for pandemic response, identifying essential roles and functions of UAS to support public health interests. It also explored optimal and sub-optimal uses and limitations for UAS, including an exploration of UAS suitability for various mission types. This task also explored UAS safety and risk mitigations for UAS operations supporting disaster response and recovery.

1 TASK 3 SUB-TASKS

The Alliance for System Safety of UAS through Research Excellence (ASSURE) project A62, Task 3, was divided into seven (7) sub-tasks. Each sub-task addresses one of seven (7) research questions relating to using UAS for disaster response and recovery. The following outlines the ASSURE A62 Task 3 sub-tasks and their research questions.

Sub-Task 3.1: What are additional use cases that should be explored for UAS supporting disaster and emergency response, recovery, mitigation, and situational awareness missions, including international use cases?

Sub-Task 3.2: What are the operational characteristics and requirements for multi-UAS operations supporting disaster and emergency response and recovery missions?

Sub-Task 3.3: What are additional use cases for UAS supporting future health pandemic response operations?

Sub-Task 3.4: What category of UAS platforms will work with each additional mission type? What are the characteristics of the optimum UAS(s) for disaster preparedness?

Sub-Task 3.5: What lessons were learned from the previous use case demonstrations?

Sub-Task 3.6: Where would UAS not be optimal for use during disasters and emergencies (i.e., manned aircraft may be more efficient at long-range response operations)?

Sub-Task 3.7: What are the risks and safety mitigations associated with UAS supporting a wide variety of disaster and emergency response use cases? What are the risks associated with the implementation of resulting recommendations by disaster and emergency response organizations?

2 RESEARCH FINDINGS FOR SUB-TASKS

The following sections address the research team's answers to the research questions. They highlight key findings from research, subject matter expertise, and additional literature reviews. The findings listed in the following section represent the primary deliverable to satisfy the requirements for ASSURE A64 Task 3 – *Identification and Analysis of Additional Use Cases and Operational Characteristics*. The following sub-sections summarize and discuss the findings for each sub-task.

2.1 Sub-Task 3.1 – Additional Use Cases

ASSURE Tasks A28 and A52 identified many significant disaster types, detailed concepts of operations, and approaches to address them using UAS. This task under the A62 effort is to expand from this original list. The original disaster use cases are not repeated here, but additional aspects are added to some cases that expand on the original.

The resulting product for this expanded use case task is the comprehensive list below, which includes the team's findings with relevant resources and notes as applicable. These notes cover UAS type, payload utilization, explanations of research and previous use cases, and the date, location, and kind of disaster. Some cases provide references to the use of UAS. The intent was not to show a full literature review for each but an example case based on previous uses. Also included are scenarios for which there was no readily available history of UAS deployment but are nonetheless applicable to the UAS operations. The list is organized by disaster types, including natural disasters, anthropogenic disasters, disaster and emergency response support operations, and other response operations. A complete list of disasters covered can be found on the following pages.

The proposal also included wording for "including international use cases." Many of the items include international references and applications. All the events and use cases included are "borderless" in their applications. They can happen anywhere in the world. No distinctions are made related to where one can apply UAS. There are different legal constructs, permissions, etc., to fly in various locations around the globe. These are not addressed here.

International use cases can also focus on the coordination and cooperative aspects. Integration and coordination are not the focus of this research question, but common language, procedures, and preestablished agreements can aid international responses, especially when time is a significant driver to support events as close to real-time as possible.

<u>Natural Disasters</u>:

- Avalanche
- Biological Incidents
- Dust storm
- Drought
- Flooding
- Heatwave
- Landslide
- Lava Flow
- Microburst
- Monitoring Invasive Species
- Tsunami
- Wildfire (revised aspects)

<u>Anthropogenic Disasters</u>:

- Animal, Agriculture, and Food Disaster
- Bombing Incidents

- Bridge Inspection/Disaster
- Building Collapse
- Crowd Control
- Culverts Under Roads
- Dam Inspection/Erosion
- Dam and Levee Security
- Debris Management
- Deforestation Monitoring
- Highway Disaster
- Hospital Radiology Emergency
- Marine Pollution
- Nuclear EMS
- Oil & Hazardous Substance Pollution
- Pipeline Leak
- Plane/Helicopter Crash
- Shipwreck
- Site Protection (Crime Scene Preservation)
- Subsidence
- Tank Car Disaster
- Water Contamination/Pollution
- Water and Wastewater Utilities

Disaster and Emergency Response Support Operations:

- Cave Rescue
- Coastal Hazard
- Debris Management Plan Development
- Emergency Medical Delivery/Communication Resilience
- Facility
- Hazardous Gases in Confined Spaces
- Lifelines, Logistics, and Supply Chain
- Mass Antibiotics Dispending

- Mass Fatalities
- Mitigation for Tribal Governments
- Offshore Safety and Emergency Response
- Population Security/Terrorism
- Post-earthquake internal Building Inspection
- Power Line Inspection
- Space Weather
- Support for People
- Swarm Search and Rescue
- Temporary Cell Networks
- Tornado

Other Response Operations:

- Evidence Collection
- Internet of Things (IoT), Artificial Intelligence (AI), and Future of UAS Autonomy
- Special Events Surveillance

Sub-sections 2.1.1, 2.1.2, 2.1.3, and 2.1.4 provide detailed descriptions of additional use cases with references to real-world examples.

2.1.1 Natural Disasters

Natural disasters represent disaster scenarios directly resulting from natural forces – e.g., weather phenomena, geological upheaval, and biological hazards. The following tables represent additional disaster use cases considered for this research. While the tables in this section do not necessarily include every possible use case, they represent a realistic overview of use cases where responders may employ UAS for response or recovery.

Table 1. Avalanche Use Case.

Avalanche			
Location	French Alps	**Date**	February 2019
Drone	Unknown (Rotary)	**Type**	Natural
Payload	Thermal and Red Green Blue (RGB) cameras		
Notes			
A drone using thermal and RBG imagery was used to inspect the results of an avalanche. The drone identified skiers attempting to help someone buried in the snow. The drone operator then alerted appropriate search and rescue, guiding them to the skier.			
Sources/References			
https://www.avalanche-center.org/News/2020/2020-10-19-France.php https://enterprise-insights.dji.com/user-stories/how-drones-benefit-the-largest-ski-area-valthorens			

Table 2. Biological Incident Use Case.

Biological Incident			
Location	Various	**Date**	Various
Drone	Various	**Type**	Natural
Payload	RGB camera		
Notes			
Biological incidents, including pathogens and similar biological threats, can spread rapidly, posing a significant risk to the people and the environment. Because the spread can be sudden, quick response is vital in mitigating the outbreak. UAS could be deployed to monitor the spread of contamination, locate viral hotspots, and determine the nature of the spread while keeping responders safe from the contaminant. From these observations, further action and isolation techniques could be performed. Following the pre-programmed flight, UAS could use thermal and RGB cameras to track the spread of contamination and identify transmission patterns. Identifying hotspots or common transmission sources could give insight into how the pathogen is transmitted and actions to prevent spread. UAS carrying medical and disinfectant supplies could be flown into affected areas without the risk of contamination from delivery personnel.			

Table 3. Dust Storm Use Case.

Dust Storm			
Location	Alvord Desert, OR	**Date**	July 20-21, 2017
Drone	3DR Solo (Rotary)	**Type**	Natural
Payload	GoPro 3 Silver and B1100-1 Pressure logger		
Notes			
A drone equipped with a GoPro 3 Silver and B1100-1 pressure logger was flown through four dust devils to support a pilot project to understand the dust devil structure better. Altitude-hold feature was disabled due to the UAS inferring altitude from barometric pressure, which is low in dust devils. Applicable takeaways from this study show that UAS can move through low-pressure, dusty, high crosswind environments within dust devils without much challenge and little damage from dust particles. This supports the potential to operate in high-dust disaster scenarios that could benefit from UAS.			
Sources/References			
https://www.mdpi.com/2072-4292/10/1/65			

Table 4. Drought Use Case.

Drought			
Location	Chinese Academy of Agriculture Science, Henan Province, China	**Date**	June - September, 2021
Drone	DJI M600 pro UAS (Rotary)	**Type**	Natural
Payload	Mica Sense Red Edge-MX (Multispectral camera) and Forward Looking Infrared (FLIR) DUO PRO R 640 (Thermal sensors)		
Notes			
Multispectral and thermal sensors and air temperature, equipped on a rotary UAS, were used to identify specific drought indices in a maize field to provide a more effective method for crop water monitoring. 14 UAS mapping operations were performed over several months, using onboard sensors to collect data to be processed and analyzed for trends.			
Sources/Reference			
https://www.sciencedirect.com/science/article/pii/S0378377423003074			

Table 5. Flood Use Case.

Flood			
Location	Various	**Date**	Various
Drone	Various (Rotary and Fixed-Wing)	**Type**	Natural
Payload	RGB camera		
Notes			
UAS, equipped with live-feed cameras as well as mapping software cameras, have been used to respond to flooding in various ways: Strategic awareness (pre-planning), structural inspection, ground search and rescue, water search and rescue, flood estimation and damage assessment, tactical awareness (supporting ground teams), and delivery missions have all been conducted. Pre-programmed flights will likely not work for this scenario unless they are generic paths. In such flooding disasters after hurricanes, there is likely to be heavy helicopter traffic in the area, so extra precautions should be taken.			
Sources/References			
https://www.fhwa.dot.gov/uas/resources/hif19019.pdf			

Table 6. Heatwave Use Case.

Heatwave			
Location	Various	**Date**	Various
Drone	Unknown (Rotary)	**Type**	Natural
Payload	Infrared and RGB camera		
Notes			
Drones equipped with infrared and visible light cameras map neighborhoods to identify which parts of cities are hot spots. This data can be used to better inform city planners and architects about what practices are most efficient at mitigating heat retention. Missions can be conducted by one or two individuals at regular periods to collect sufficient data.			
Sources/References			
https://www.nutanix.com/theforecastbynutanix/industry/how-uav-thermal-cameras-are-mapping-heat-in-cities			

Table 7. Landslide Use Case.

Landslide			
Location	Oso, Washington	**Date**	March 22, 2014
Drone	AirRobot AR100B (Rotary), Insitu Scan Eagle (Fixed-Wing), and PrecisionHawk Lancaster (Fixed-Wing)	**Type**	Natural
Payload	Light Detection And Ranging (LIDAR) and Thermal cameras		
Notes			
Geologists deployed three drones to comprehensively understand the event and assess the eminent risk and loss of life to responders from further slides and floods. Initial imagery of the event was used to aid first responders in anticipating and mitigating ongoing flooding. Following 2D and 3D scans provided responders with an accurate landscape reconstruction. Imaging continued over several days to predict future slide movement. A short runway was needed for the fixed-wing UAS, and the Sheriff's Urban Search and Rescue Office granted temporary flight access.			
Sources/References			
https://core.ac.uk/download/pdf/33148267.pdf			

Table 8. Lava Flow Use Case.

Lava Flow			
Location	La Palma Island, Spain	**Date**	September - December, 2021
Drone	DJI Mavic 2 Pro quadcopter and Custom hexacopter	**Type**	Natural
Payload	Mica Sense RedEdge-MX (Dual Multispectral Camera), FLIR Vue Pro 19 mm (Radiometric Thermal Camera), and an RGB Hasselblad L1D-20c Camera with 1” CMOS and 20 MP		
Notes			
Using RGB, thermal, and multispectral sensors, UAS monitored lava flow advances and their environmental consequences. The Digital Elevation Model (DEM) the authors derived was able to simulate future lava flow paths with 70% accuracy. This could be used in real-time to improve response and evacuation times to advancing lava flow. Pix4D mapper was used to collect thermal, 2D/3D imaging, and topographic data, which was interpolated to create the DEM.			
Sources/References			
https://digital.csic.es/bitstream/10261/285580/1/Unmanned_aerial_vehicles.pdf			

Table 9. Microburst Use Case

Microburst			
Location	Various	**Date**	Various
Drone	Various (Rotary)	**Type**	Natural
Payload	Thermal camera, RGB camera, and LIDAR		
Notes			
A microburst is a sudden, intense downdraft of air associated with large thunderstorms. These events are severe enough to cause structural collapses, potentially trapping and injuring people. The resulting damage and threat of falling debris can make the area extremely dangerous for first responders. To combat this, UAS can be deployed to assess damage, identify areas of severe impact, and locate survivors, ultimately aiding in a quicker and safer recovery response. Rotary UAS equipped with thermal cameras could locate missing or buried people more quickly following an event. In conjunction with live-fed cameras, this could be used for real-time aid to first responders in rapid search and rescue or to navigate falling debris. Mapping operations using standard RGB cameras and LIDAR could be used to assess damage costs and secure recovery funds.			

Table 10. Invasive Species Monitoring Use Case.

Monitoring Invasive Species			
Location	Blandy Experimental Farm, Virginia	**Date**	April - June, 2020
Drone	DJI Matrice 600 (Rotary)	**Type**	Natural
Payload	Headwall's Nano-Hyperspec (Spectroscopic camera)		
Notes			
This use case involves using spectroscopic imaging to identify and control the spread of invasive plant species into farmlands. A single flight operation was performed over two fields, taking spectroscopic images. The images indicate plant chemical and structural properties, which were then used to identify specific invasive plants. Flights could be performed periodically by a small one-to-two-person team to track the spread of said invasive plants.			
Sources/References			
https://vsgc.odu.edu/wp-content/uploads/2021/11/Huelsman.pdf https://www.mdpi.com/2504-446X/7/3/207#:~:text=In%20order%20to%20effectively%20manage,this%20information%20from%20large%20areas			

Table 11. Tsunami Use Case.

Tsunami			
Location	Onagawa Town, Japan	**Date**	March 11, 2011
Drone	DJI Phantom 2 vision plus (Rotary)	**Type**	Natural
Payload	RGB camera		
Notes			
Global Positioning System (GPS)-guided UAS aerial shooting and 3D mapping of infrastructure affected by tsunamis from the 2011 Tohoku earthquake. Several flight patterns and techniques are analyzed in the article to determine which produces the best model. The models can be used to determine the intensity of the disaster and adapt future infrastructure. There was no additional payload outside the onboard camera. Operations used typical flight mapping software and procedures.			
Sources/Reference			
https://www.researchgate.net/publication/283506944_Construction_of_3D_models_of_buildings_damaged_by_earthquakes_using_UAV_aerial_images			

Table 12. Wildfire Use Case.

Wildfire			
Location	Northern California	**Date**	August 2021
Drone	Various (Rotary, Vertical Take-Off and Landing (VTOL))	**Type**	Natural
Payload	Infrared and RGB camera		
Notes			
During the California wildfires, UAS equipped with thermal imaging and RGB cameras were used to capture heat signatures and monitor the movement of the fire, helping firefighters determine where to establish fire-containment lines. UAS provided critical information on fire spread and terrain, enabling safer and more efficient decision-making. These UAS also assisted in mapping operations, offering real-time data to guide the deployment of resources and personnel.			
Sources/References			
https://www.nasa.gov/aeronautics/at-california-blazes-nasa-team-observes-how-drones-fight-wildfire/			

2.1.2 Anthropogenic Disasters

Anthropogenic disasters are influenced by humankind. These disasters may result directly from human action, inaction, or a combination. They reflect disaster scenarios that may result from intentional acts, carelessness, or a need to monitor conditions to prevent a disaster scenario that may result from human influences on environmental factors. The following tables represent anthropogenic disasters considered for this research.

Table 13. Animal, Agricultural, and Food Disaster Use Case.

Animal, Agricultural, and Food Disasters			
Location	Various	**Date**	Various
Drone	X8 octocopter (Rotary) and custom FX79 airframe (Fixed-Wing)	**Type**	Anthropogenic
Payload	RGB camera		
Notes			
Mapping operations flown with rotary and fixed-wing UAS were performed to track the movement and population of several Australian and Polar animals. Using standard RGB cameras, herds of the animals were tracked and then counted to monitor population numbers. This method proved more accurate than ground counting, consistently locating more animals.			
Sources/References			
https://www.nature.com/articles/srep22574 https://besjournals.onlinelibrary.wiley.com/doi/full/10.1111/2041-210X.13829			

Table 14. Bombing Incident(s) Use Case.

<u>Bombing Incidents</u>			
Location	Various	**Date**	Various
Drone	Various (Rotary)	**Type**	Anthropogenic
Payload	LIDAR and IR cameras		
Notes			
Bombing incidents often result in widespread damage and pose significant risks to first responders due to potential secondary devices, structural instability, and hazardous materials. UAS can be deployed to survey the area safely and efficiently, providing crucial information on the extent of the damage, identifying potential secondary threats, and assessing hazardous conditions. Rotary UAS equipped with high-resolution cameras and LIDAR can be utilized to perform aerial surveys of the incident site, identifying structural damage and hazardous materials. Infrared (IR) cameras can detect heat signatures indicating secondary devices or ongoing fires.			

Table 15. Bridge Inspection/Disaster Use Case.

<u>Bridge Inspection/Disaster</u>			
Location	Baltimore, MD	**Date**	March 26, 2024
Drone	Various (Rotary)	**Type**	Anthropogenic
Payload	Thermal and RGB camera		
Notes			
During the recent Baltimore Bridge collapse, in which a container ship lost power, causing it to ram into the supports near the middle of the bridge, local authorities and response teams were called to the scene to conduct a search and rescue mission to retrieve six men who were on the bridge. The Coast Guard utilized boats and helicopters to find those on the bridge at the time of collapse, but due to the temperature of the water and the length the men were missing, they were presumed to be dead. UAS could expedite the search for survivors in similar time-sensitive scenarios due to their deployment speed, mobility, and reduced crew requirements. UAS can fly closer, safer, faster, and livestream video with higher quality than a helicopter, making them more desirable in similar scenarios.			
Sources/References			
https://www.bbc.com/news/world-us-canada-68663318			

Table 16. Building Collapse Use Case.

Building Collapse			
Location	Surfside, FL	**Date**	June 24, 2021
Drone	Various (Rotary)	**Type**	Anthropogenic
Payload	Thermal and RGB camera		
Notes			
In the aftermath of the third most fatal building collapse in US history, 304 UAS missions were conducted to assess the amount of damage, identify weak spots, and search for missing people. Many DJI and Autel rotary UAS and a tethered Fotokite system were utilized. Due to the collapse occurring around midnight, DJI Mavic 2 Enterprise Dual drones equipped with thermal and spotlight payloads were used. However, the integrated thermal system was of inadequate resolution, and the spotlight and visible light camera provided a very narrow field of view. UAS were primarily used to create 3D maps to assist rescue efforts.			
Sources/References			
https://spectrum.ieee.org/building-collapse-surfside-robots			

Table 17. Crowd Control Use Case.

Crowd Control			
Location	Various	**Date**	Various
Drone	Various (Rotary)	**Type**	Anthropogenic
Payload	RGB camera and speaker array		
Notes			
Crowds often gather for various events or protests, sometimes leading to challenging and potentially hazardous situations for participants and law enforcement. This makes the immediate area challenging to monitor and control effectively. To address this, UAS can be deployed to observe crowd movements, identify potential hotspots, and monitor the overall situation to aid in a safe and efficient response. Rotary UAS, equipped with high-resolution cameras and real-time video feeds, can provide live monitoring and situational awareness. Aerial surveillance can help map crowd density and movement patterns, guiding law enforcement to potential trouble spots and allowing for better resource allocation. Additionally, UAS equipped with loudspeakers can communicate with the crowd.			

Table 18. Culvert Use Case.

Culverts Under Roads			
Location	Various	**Date**	Various
Drone	Various (Rotary)	**Type**	Anthropogenic
Payload	RGB camera and LIDAR		
Notes			
The structural integrity of culverts running underneath roadways is critical regarding safety considerations. UAS can be used to quickly determine if a culvert is blocked with sediment, is housing a person, or is aging poorly. During rainy seasons, overhead views can aid in determining if a culvert is underperforming. Similarly, UAS can be flown down to the same level as the culvert to inspect it for debris or possibly people, allowing ground crews to safely inspect the culvert from the road, minimizing the potential risk of an altercation. UAS can also be utilized to create a 3D map of the culvert that can serve as a reference to compare how the culvert is aging. Rotary UAS equipped with an RGB camera would be best suited to quickly observe culvert efficiency or contents within a culvert. Similarly, rotary UAS with an RGB camera and a LIDAR sensor can be flown through a culvert, creating a 3D map to identify current and potential weak spots that would improve the accuracy and efficiency of future repair.			

Table 19. Dam Inspection/Erosion Use Case.

Dam Inspection/Erosion			
Location	Seattle, WA	**Date**	N/A
Drone	Unknown (Rotary)	**Type**	Anthropogenic
Payload	RGB camera		
Notes			
The Diablo Dam in Seattle recently employed UAS to map over 80 million data points from the arch dam, spillways, and rock abutments to create a 3D dam model. The UAS also took multiple high-definition photographs that future inspections can be compared against to monitor the progression of surface cracks.			
Sources/References			
https://www.trihydro.com/news/news-details/2019/05/28/using-drones-for-safer-dam-inspections-and-evaluations			

Table 20. Dam and Levee Security Use Case.

Dam and Levee Security			
Location	Various	**Date**	Various
Drone	Various	**Type**	Anthropogenic
Payload	Various (RGB cameras, LIDAR, and thermal cameras)		
Notes			
Dams and levees are critical infrastructures that, if compromised, can lead to catastrophic flooding and significant damage to the environment and human life. The immediate area surrounding a compromised dam or levee can be extremely hazardous to first responders due to potential structural failure and flooding. UAS can monitor the structure's integrity, identify breaches, and assess the affected area to facilitate a safe and efficient response. Fixed-wing UAS equipped with high-resolution cameras and LIDAR sensors can inspect dams and levees, identifying cracks, erosion, and other signs of structural weakness. Additionally, rotary UAS equipped with thermal imaging and moisture detection sensors can be flown in to detect water seepage and other indicators of structural compromise.			

Table 21. Debris Management Use Case.

Debris Management			
Location	Various	**Date**	Various
Drone	Unknown (Rotary)	**Type**	Anthropogenic
Payload	Thermal and RGB camera		
Notes			
When equipped with thermal cameras, UAS are great at monitoring and identifying hot spots in landfills that may be locations of future fire hazards. If these locations aren't found, much less addressed, this could be catastrophic for the landfill as a fire would release many pollutants into the air.			
Sources/References			
https://www.recyclingproductnews.com/article/41556/5-uses-for-drones-in-recycling-and-waste-management			

Table 22. Deforestation Monitoring Use Case.

Deforestation Monitoring			
Location	Barro Colorado Island, Panama	**Date**	March 2022
Drone	Unknown (Fixed-Wing)	**Type**	Anthropogenic
Payload	RGB camera and LIDAR		
Notes			
Using standard RGB cameras, several mapping operations were performed to monitor the canopy coverage of the rainforest and track changes. These images were also used to study leaf phenology. The article states that the operation could be significantly improved using LIDAR cameras. A short runway was needed for takeoff and landing.			
Sources/References			
https://news.mongabay.com/2022/03/researchers-turn-to-drones-for-that-big-picture-view-of-the-forest-canopy/#:~:text=They%20are%20also%20training%20communities,t%20be%20seen%2C%20Spina%20says			

Table 23. Highway Disaster Use Case.

Highway Disaster			
Location	Various	**Date**	Various
Drone	DJI Inspire 1, Phantom 3, Various Other (Rotary)	**Type**	Anthropogenic
Payload	RGB camera		
Notes			
UAS have a place in the highway system and can be useful in different scenarios. There is research on UAS being used for photogrammetry to reconstruct traffic accident scenes, as well as vehicle detection and extraction of traffic parameters. Drones are even used for road safety inspections, such as creating a 3D map of the road's surface. Highway Patrol officers or the Department of Transportation can perform these use cases.			
Sources/References			
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7527789/#b0270 https://ops.fhwa.dot.gov/tim/docs/EDC-6_Factsheet_TIM_UnmannedAircraft_v2_508.pdf			

Table 24. Hospital Radiology Use Case.

Hospital Radiology Emergency			
Location	Various	**Date**	Various
Drone	Various (Rotary)	**Type**	Anthropogenic
Payload	Radiation detection sensors and thermal imaging		
Notes			
Hospital radiology departments often handle materials that can be hazardous in the event of an emergency, such as radioactive substances or malfunctioning equipment. This makes the immediate area potentially dangerous for medical personnel and patients. To address this, UAS can assess the situation remotely, identify any leaks or damage, and monitor the affected areas to ensure a safe and controlled response. Rotary UAS equipped with radiation detection sensors can be used to detect and measure radiation levels. Thermal imaging cameras can help identify overheating equipment or areas with unusual thermal signatures.			

Table 25. Marine Pollution Use Case.

Marine Pollution			
Location	Oregon State University and Barrier Islands, Texas	**Date**	December 2021
Drone	Various (Rotary and VTOL Fixed-Wing)	**Type**	Anthropogenic
Payload	Polarimetric imaging and RGB camera		
Notes			
A polarimetric Imaging camera was mounted on a DJI Matrice 300, which could capture well-exposed images of different kinds of debris and trash that washed up along the coastline. These images were used to train a machine learning model to identify organic debris from manmade pollution automatically. This capability suggests a future where UAS could respond to capsized vessels and identify relevant debris items.			
Sources/References			
https://library.oarcloud.noaa.gov/noaa_documents.lib/NOS/NCCOS/TM_NOS_NCCOS/nos_nccos_312.pdf			

Table 26. Nuclear EMS Use Case.

<table>
<tr><td colspan="4"><u>Nuclear EMS</u></td></tr>
<tr><td>Location</td><td>Ōkuma, Fukushima, Japan</td><td>Date</td><td>March 11, 2011</td></tr>
<tr><td>Drone</td><td>Honeywell T-Hawk (Rotary) and Custom (Fixed-Wing)</td><td>Type</td><td>Anthropogenic</td></tr>
<tr><td>Payload</td><td colspan="3">RBG camera and radiation detectors</td></tr>
<tr><td colspan="4">Notes</td></tr>
<tr><td colspan="4">Following the near meltdown of the Fukushima Daiichi nuclear plant, UAS were used on several occasions to perform radiation monitoring, structural mapping, and inspection. This allows for structural assessment and location of radiation hot spots along with real-time imagery, which gives inspectors better situational awareness.</td></tr>
<tr><td colspan="4">Sources/References</td></tr>
<tr><td colspan="4">https://www.osti.gov/servlets/purl/1431749
https://www.pnnl.gov/news-media/drones-fly-low-and-slow-radiation-detection</td></tr>
</table>

Table 27. Oil & Hazardous Substance Use Case.

<table>
<tr><td colspan="4"><u>Oil & Hazardous Substance Pollution</u></td></tr>
<tr><td>Location</td><td>Various</td><td>Date</td><td>Various</td></tr>
<tr><td>Drone</td><td>Various (fixed-wing and rotary)</td><td>Type</td><td>Anthropogenic</td></tr>
<tr><td>Payload</td><td colspan="3">IR camera and optical gas sensor</td></tr>
<tr><td colspan="4">Notes</td></tr>
<tr><td colspan="4">Hazardous material released into the environment can severely impact the environment and the people inhabiting it. This can make the affected area extremely dangerous for residents and first responders. UAS could be deployed to monitor the spread of pollution, identify affected wildlife, and assess damage to structures and ecosystems, thus aiding in creating a safer and more efficient response to the disaster.

Mapping operations could be performed with fixed-wing and rotary UAS to cover the affected area and monitor the spread of the pollution. Specialized cameras, such as IR or Optical Gas Imaging, could be fitted to UAS to differentiate the pollutant from the environment and identify current and future affected areas. Similarly, gas sensors could be installed for airborne incidents. Evaluation of both the structural and environmental damage could be assessed from these operations.</td></tr>
</table>

Table 28. Pipeline Leak Use Case.

Pipeline Leak			
Location	Various	**Date**	Various
Drone	Various (Rotary)	**Type**	Anthropogenic
Payload	Thermal, infrared, and RGB camera		
Notes			
Those in the oil and gas industry use UAS equipped with thermal, infrared, and visual cameras to detect leaks earlier and more accurately than traditional methods. Due to the static nature of pipelines, a flight can be programmed over a pipeline section and executed at regular intervals to monitor potential leak locations. These missions can collect and store imaging data or stream it to the ground team to assess the feed in real time.			
Sources/References			
https://www.flytbase.com/blog/bvlos-pipeline-inspection-using-nested-drone-system#simplify-early-detection-of-pipeline-leaks			

Table 29. Plane/Helicopter Crash Use Case.

Plane/Helicopter Crash			
Location	United Kingdom (various)	**Date**	2014 (Various)
Drone	DJI Phantom 2 Vision Plus (Rotary) and DJI Inspire Pro (Rotary)	**Type**	Anthropogenic
Payload	RGB camera		
Notes			
The United Kingdom Air Accidents Investigation Board (AAIB) outlines previous UAS use cases for aircraft crash sites, such as 3D mapping, recovery aid, and reconnaissance. Mapping operations are performed to create Ortho mosaic 3D models so that the crash site can be accurately recorded for locating wreckage and future briefings. The AAIB also uses drones to aid and supervise wreckage recovery.			
Sources/References			
https://skybrary.aero/sites/default/files/bookshelf/4446.pdf			

Table 30. Shipwreck Use Case.

Shipwreck			
Location	Lake Huron	**Date**	April 2017
Drone	Phantom4 quadcopter and Unknown (Rotary)	**Type**	Anthropogenic
Payload	RGB camera		
Notes			
Responding to shipwreck 'Norman' and other historic wrecks, UAS used high-resolution photographs to identify ship remains in shallow waters. Several low-altitude operations were flown to map the waters near the shore.			
Sources/References			
https://sanctuaries.noaa.gov/news/may17/getting-a-birds-eye-view-of-thunder-bay-national-marine-sanctuary.html			

Table 31. Site Protection Use Case.

Site Protection (Crime Scene Preservation)			
Location	Various	**Date**	Various
Drone	Various (Rotary)	**Type**	Anthropogenic
Payload	RGB camera		
Notes			
Preserving crime scenes is paramount to helping authorities accurately examine the crime scene for evidence or potential clues where foreign objects may obscure the truth. UAS can help to secure the perimeter of a large crime scene area, especially in cases where the actual crime scene perimeter is vague, and people may not realize they are entering a crime scene. Launching UAS around the perimeter would allow authorities to surveil and stop people trying to enter the crime scene. This method applies to large crime scene areas where the perimeter may not be within visual line of sight due to terrain but where a UAS would be within line of sight. Once an active crime scene is established, police officers can launch rotary UAS equipped with standard RGB cameras to survey the perimeter of the crime scene. If people are determined to be too close to the perimeter or trying to enter the crime scene, another officer can be dispatched to the area to stop intruders.			

Table 32. Subsidence Use Case.

Subsidence			
Location	Shanxi Province, China	**Date**	March 2020 – January 2022
Drone	Feima D2000 (Rotary)	**Type**	Support / Anthropogenic
Payload	LIDAR and RGB camera		
Notes			
A UAS was equipped with a visible camera and LIDAR sensor to monitor subsidence induced by mining operations. Five datasets were compiled between March 2020 and January 2022, including one LIDAR dataset and four photogrammetric datasets. The study results show that data collected by a UAS is adequate for identifying characteristics associated with subsidence behavior. Flights must be flown with sufficient time between flights due to the long-term nature of subsidence and to improve accurate data collection by maximizing the differences between datasets.			
Sources/References			
https://www.mdpi.com/2072-4292/15/2/374			

Table 33. Tank Car Disaster Use Case.

Tank Car Disasters			
Location	Various	**Date**	Various
Drone	Various (Rotary)	**Type**	Anthropogenic
Payload	IR cameras and gas detection sensors		
Notes			
Tank cars often transport material that may be flammable or harmful to people and the environment. This makes the immediate area surrounding the car very dangerous to first responders. To combat this, UAS could be deployed to observe damage to the car, potential leaks, and any affected area to aid in a safe response to the disaster. Rotary UAS equipped with IR cameras have been used in similar disasters to identify pollutants through their thermal infrared signatures. Mapping operations could be performed to assess damage to the car and surrounding area, guide first responders, and determine cost evaluation. Finally, gas detection sensors could be flown in on rotary UAS to identify leaks and areas of more significant health risk.			

Table 34. Water Contamination/Pollution Use Case.

Water Contamination/Pollution			
Location	Campania region, Italy	**Date**	Unknown, 2014
Drone	Unknown (Rotary)	**Type**	Anthropogenic
Payload	Forward-Looking Infrared (FLIR) and thermal IR camera		
Notes			
In Italy, illegally using the waterways to dispose of hazardous waste is very common, leading to severe health and safety concerns. In response, UAS have been used to identify and track waste in the water and any unauthorized waste burning. These "anomalies" in the water can be identified through their thermal infrared signatures. Using FLIR IR cameras and the Intelligent Data Extraction System to perform analysis, a single UAS can perform a mapping operation using thermal imagery to locate the pollutants and their source. Through this technique, Italy has reduced the incidence of illegal pollution.			
Sources/References			
https://www.witpress.com/Secure/elibrary/papers/WM14/WM14019FU1.pdf			

Table 35. Water and Wastewater Utilities Use Case.

Water and Wastewater Utilities			
Location	Various	**Date**	Various
Drone	Various (Rotary)	**Type**	Anthropogenic
Payload	Various (Specialized sensors)		
Notes			
Water utilities are essential for public health and sanitation, such that even momentary stoppage can severely impact the community. Rapidly addressing any damage or problems to these systems is critical. These systems can also deal with hazardous chemicals and waste, which can be hazardous to first responders. UAS could provide a quick, safe solution to these issues, allowing for inspecting and monitoring damaged systems. This would ensure that the water utilities are restored quickly while maintaining the safety of the workers. In response to water/waste pipeline damage, UAS could inspect the pipe autonomously. A rotary drone with specialized sensors could follow a pre-programmed path and identify a leak point. These same sensors could be used to determine the toxicity of the surrounding area so that proper safety measures can be taken to protect workers. Regularly scheduled UAS missions could then be performed to ensure the upkeep of the pipeline or treatment facility and prevent any future shutdown.			

2.1.3 Disaster and Emergency Response Support Operations

Disaster and emergency response support operations support ongoing efforts to respond to the aftermath of a disaster event. Such use cases may involve rescuing individuals who may be trapped, disaster scene mapping, gas sampling, or other use cases that aid responders in saving lives and mitigating the effects of a disaster scenario. The research team considered the following additional use cases for this research.

Table 36. Cave Rescue Use Case.

Cave Rescue			
Location	Northern Thailand	**Date**	June 16, 2018
Drone	Unknown (Rotary)	**Type**	Support
Payload	Thermal, RGB, and night-capable cameras		
Notes			
When beginning the attempt to rescue 12 children and their soccer coach, it became apparent the lack of accuracy of the old existing cave system maps. Drones were deployed to perform several mapping missions to collect topographic data. 2D maps, 3D maps, and cave cross sections were created to aid the recovery efforts and estimate remaining oxygen. On-board lights or night-capable photography must be used in the dark environment.			
Sources/References			
https://www.gim-international.com/content/article/the-behind-the-scenes-story-of-the-thailand-cave-rescue			

Table 37. Coastal Hazards Use Case.

Coastal Hazards			
Location	Louisiana Coast	**Date**	September 2021
Drone	Unknown	**Type**	Support
Payload	RGB camera		
Notes			
In response to Hurricane Ida, the Coast Guard deployed several SR-UAS to aid in operations. Aids To Navigation (ATON) were dislodged from their appropriate position off the coast. These are channel markers on which the shipping industry relies to navigate. UAS were used to locate and verify that the ATONs were in their appropriate location. A flight operator would manually fly and observe ATON recording their position.			
Sources/References			
https://www.mycg.uscg.mil/News/Article/2841972/coast-guard-drones-can-see-underwater-and-inside-vessels-during-response-to-hur/#:~:text=During%20Hurricane%20Dorian%2C%20for%20example,had%20drones%20not%20been%20used.			

Table 38. Debris Management Use Case.

Debris Management Plan Development			
Location	Various	**Date**	Various
Drone	Various (Rotary and Fixed-Wing)	**Type**	Support
Payload	LIDAR and RGB camera		
Notes			
UAS can aid in building a detailed debris management plan. They may provide clear maps and an overview of the field before clean-up. During recovery, the UAS can monitor workers and alert them of any loose debris that may pose a threat. LIDAR-equipped drones could survey the debris field and produce high-fidelity 3D maps. Coupled with thermal cameras, potential ignition sources, and other hazards could be identified within the debris. These mapping missions would provide a detailed view of the debris field to develop a well-informed plan. For larger areas, fixed-wing drones would be best suited for mapping. Furthermore, during recovery operations, a rotary drone could use live-feed cameras to monitor the movement of debris and identify any unforeseen hazards to protect the workers onsite.			

Table 39. Emergency Medical Delivery/Community Resilience Use Case.

Emergency Medical Delivery/Community Resilience			
Location	Rwanda	**Date**	Ongoing
Drone	Custom (Fixed-Wing)	**Type**	Support
Payload	Medical supplies (3-lb)		
Notes			
To mitigate the time required to receive medical treatment in rural Rwanda, Zipline uses fixed-wing drones to deliver blood, vaccines, and anti-venom in as little as 15 minutes. Ground-based transportation takes hours to reach certain areas, which may be too late for certain emergencies. For this operation, the drones must be able to travel long distances (75 miles round-trip) and accurately release a 3-lb payload in flight. A short runway and proper storage/insulation will be required. In this way, UAS could improve community resilience and recovery to existing and future disasters.			
Sources/References			
https://www.dronesinhealthcare.com/#:~:text=For%20many%20conditions%2C%20drone%20technology,to%20the%20home%20by%20drone			

Table 40. Facility Support Use Case.

Facility			
Location	Various	**Date**	Various
Drone	Various (Rotary)	**Type**	Support
Payload	RGB camera and thermal camera		
Notes			
University and college campuses often contain a dense population and a variety of facilities that could be vulnerable to various emergencies, such as fires, chemical spills, or natural disasters. This makes the immediate area very challenging and potentially hazardous for first responders. To enhance safety and efficiency, UAS could be deployed periodically to monitor campus facilities, detect hazards, and assess the extent of damage during and after an emergency. Rotary UAS equipped with high-resolution cameras and thermal imaging can be used to identify hotspots, structural damages, and hazardous materials. Real-time aerial surveillance could be performed to provide situational awareness and guide first responders to the most critical areas. Gas detection sensors on rotary UAS could also identify chemical leaks and areas with heightened health risks. Mapping operations could also be conducted to evaluate the impact on campus facilities and aid in recovery and cost assessment efforts.			

Table 41. Hazardous Gas Use Case.

Hazardous Gases in Confined Spaces			
Location	Various (Africa)	**Date**	N/A
Drone	Custom (Rotary)	**Type**	Support
Payload	Arduino and various sensors to locate gas and vibrations		
Notes			
Most African economies are supplied through crude oil in pipes, where unintended leaks have taken nearly 3000 lives. The ability to quickly detect and respond to pipe leakage can be integrated into UAS using vibration and gas sensors. The drone is intended to fly autonomously in response to event signals transmitted by gas and vibration sensors.			
Sources/References			
https://onlinelibrary.wiley.com/doi/10.1155/2021/1300740			

Table 42. Logistics and Supply Chain Use Case.

Lifelines, Logistics, and Supply Chain			
Location	Various	**Date**	Various
Drone	Various (Rotary and fixed-wing)	**Type**	Support
Payload	RGB camera		
Notes			
Lifelines, logistics, and supply chains often involve critical materials and resources for emergency response and daily life. Disruption could leave vulnerable populations without vital supplies. UAS could combat this by surveying the damage, identifying blockages, and monitoring the distribution of said resources, contributing to a quicker and safer response to restore supply flow. UAS could be deployed using onboard RGB cameras to survey infrastructure damage, mapping the affected area to first responders. UAS could be used to travel downstream to identify any potential source or resolution to blockage. Also, they could be used to monitor the resources as they are delivered to identify failure before it occurs and prevent any unnecessary blockage.			

Table 43. Antibiotics Dispensing Use Case.

<u>Mass Antibiotics Dispensing</u>			
Location	Various	**Date**	Various
Drone	Various (Rotary)	**Type**	Support
Payload	RGB camera and antibiotics		
Notes			
Rapid distribution must be maintained to dispense antibiotics on a mass scale to control or prevent outbreaks. Due to the risk of congestion and exposure, bringing in many people to support can be difficult and unsafe. UAS can be used to fill these gaps. By delivering antibiotics, monitoring distribution points, and performing crowd control, UAS could significantly improve existing practices. It is recommended that fixed-wing drones be used to deliver antibiotics because they can carry larger payloads. For short delivery and monitoring, rotary UAS will be more useful. Dispensary stations will be necessary and high-traffic; to mitigate contamination, the UAS could monitor the flow of people in and out of dispensary locations using live-feed cameras to identify any security risks.			

Table 44. Mass Fatalities Use Case.

<u>Mass Fatalities</u>			
Location	Various	**Date**	Various
Drone	Various (Rotary)	**Type**	Support
Payload	RGB camera and thermal camera		
Notes			
In mass fatalities of various causes, locating and identifying the deceased is of high priority but can be challenging depending on the circumstances. UAS can be utilized to make this process much more manageable. Providing a bird's-eye view to authorities and first responders, UAS are excellent at delivering real-time data in rugged terrain or through smoke/haze when equipped with thermal cameras. Rotary UAS with live high-resolution RGB and thermal cameras allow first responders to accurately and efficiently survey a disaster site to locate bodies and potentially discern those alive from those deceased. This ability to quickly identify survivors can allow first responders to construct better response plans, targeting survivors first.			

Table 45. Tribal Governments Use Case.

Mitigation for Tribal Governments			
Location	Various	**Date**	Various
Drone	Various (Rotary)	**Type**	Support
Payload	Cellular UEs		
Notes			
UAS can be used to determine and assess potential hazard locations such as forest fires or high-risk flash flood areas. UAS can also be used in emergencies to deploy a temporary cellular network, allowing short-term communications throughout the tribal region. This network can inform people of necessary evacuations, allow coordination with other local governments, or notify people of where emergency supplies can be found. Tribal governments can utilize rotary UAS equipped with cellular UEs, and relays can be deployed to create a temporary network in disaster scenario settings. Tribal governments may benefit significantly from this capability because smaller locales may not have the preexisting infrastructure that larger towns or cities have, and the infrastructure there may be more easily knocked out.			

Table 46. Offshore Safety and Emergency Response Use Case.

Offshore Safety and Emergency Response			
Location	Santa Barbara, CA	**Date**	July 2023
Drone	Unknown (Rotary)	**Type**	Support
Payload	Thermal and RGB camera		
Notes			
In 2023, the Office of Response and Restoration and the Coast Guard teamed up to optimize the Coast Guard's current use of UAS to better support oil spill responses. The program taught students how to use UAS to detect and map oil on the water's surface. Pilots were trained to look for and identify the location of oil slicks, but in cases where the oil was difficult to identify, pilots could use thermal imagery instead. Once the oil is identified, the pilot will capture images overlapping at least 50% of the previous image to create a map. This process might benefit from a dedicated mapping and image collection UAS. Flights would be conducted as needed soon after the oil spill is realized.			
Sources/References			
https://blog.response.restoration.noaa.gov/it-all-begins-flight-operationalizing-uncrewed-aircrafts-support-oil-spill-response-recovery-and			

Table 47. Population Security Use Case.

Population Security/Counterterrorism			
Location	Various	**Date**	Various
Drone	Various (Rotary)	**Type**	Support
Payload	RGB camera, LIDAR, and thermal sensors		
Notes			
Once an act of terrorism has occurred, the resulting casualties can be significant, and the ensuing panic only furthers the risk and challenge for law enforcement. UAS can be involved in each stage of an attack: attack prevention, mitigation, and investigation. Before a large gathering or event, rotary UAS can map the area and identify potential risk areas. Authorities could use this information to place security in ideal locations to mitigate risk, sweep for possible threats, and gain a more holistic view of the event. During the event, a UAS operator could provide live monitoring of these areas, identifying and alerting any suspicious activity. If a threat is ongoing, UAS could monitor the exfiltration of attendees and guide law enforcement to the continuing threat. Following an attack, mapping could assess damage and identify security failures. Standard RGB, LIDAR, and thermal cameras would be of use.			

Table 48. Post-Earthquake Inspection Use Case.

Post-Earthquake Internal Building Inspections			
Location	Various	**Date**	Various
Drone	Various (Rotary)	**Type**	Support
Payload	RGB camera		
Notes			
While external building inspection using UAS is common, performing mapping within the damaged building has not been recorded to date. Doing so would give a more in-depth and holistic view of any structural damage to a building. This could aid in performing safer recovery efforts and more accurate cost/damage evaluations. Several rotary drones exist within the market that are designed for flight in tight-space inspection operations. External cages and similar features make them resilient to bumps and crashes. Mapping within a structure could be done with greater success. A standard RGB camera for 3D mapping would allow for adequate damage analysis.			
Sources/References			
https://www.flyability.com/blog/internal-inspection https://www.mdpi.com/2220-9964/9/1/14			

Table 49. Power Line Inspection Use Case.

Power Line Inspections			
Location	N/A	**Date**	N/A
Drone	Unknown (Rotary)	**Type**	Support
Payload	RGB Camera		
Notes			
UAS have often been used to increase safety and lower costs compared to traditional power line inspections. Regular inspections with UAS are faster and more efficient at identifying potential hazards near the power line. Similarly, UAS are the quickest way to identify and locate the issue during a power outage in the event of extreme winds, floods, or fires.			
Sources/References			
https://www.skydio.com/blog/how-drones-are-used-for-inspection https://www.theutilityexpo.com/news/drones-are-driving-success-in-the-utility-industry			

Table 50. Space Weather Use Case.

Space Weather			
Location	Various	**Date**	Various
Drone	Various (Rotary)	**Type**	
Payload	Cellular communication equipment and RGB camera		
Notes			
UAS systems could provide several advantages to first responders and electrical workers looking to support recovery efforts from blackouts caused by space weather. UAS could aid in grid inspection by flying mapping missions to locate areas of concern and tripped breakers. Also, communication is commonly damaged during these storms, and establishing temporary communication networks using drones may help first responders communicate better. Rotary UAS carrying communication equipment such as cellular Base Stations (BS), User Equipment (UE), and relays could adequately support temporary communications during recovery efforts. The UAS could also perform mapping operations to inspect damage to the grid using an RGB camera.			
Sources/References			
Practical_Aspects_Standardization_Advancements_Regulation_and_Security_Challenges			

https://hal.science/hal-02786557 https://www.cbsnews.com/news/how-do-solar-storms-affect-electronics-gps-power-grid-internet/

Table 51. People Support Use Case.

Support for People			
Location	Various	**Date**	Various
Drone	Various (Rotary)	**Type**	Support
Payload	RGB camera and thermal camera		
Notes			
Ensuring the safety and well-being of all individuals, including children and individuals with special needs, is paramount during disaster scenarios. UAS can be crucial in evacuation planning and response by providing real-time aerial assessments of affected areas. This allows emergency planners to devise efficient evacuation routes and identify safe zones for vulnerable populations. Rotary UAS equipped with high-resolution cameras can monitor disaster zones to identify obstacles, damaged infrastructure, and safe passages for evacuation. Additionally, UAS equipped with thermal imaging can locate individuals who may be trapped or need assistance, including people with disabilities and children.			

Table 52. Swarm Search and Rescue Use Case.

Swarm Search and Rescue			
Location	Various	**Date**	Various
Drone	Unknown (Fixed Wing, Rotary)	**Type**	Support
Payload	Infrared, Multi-Spec, EO, and Lidar		
Notes			
Researchers have started looking into Layered Search and Rescue Algorithms for using multi-UAS deployment missions. This algorithm autonomously starts the drone's missions in the center, where survivors will most likely be found, and moves outward. Agencies like the Coastguard already use UAS for SAR, utilizing fixed-wing and multi-rotary.			
Sources/References			
https://ieeexplore.ieee.org/document/8695011			

https://www.dco.uscg.mil/Portals/9/CG-5R/nsarc/SAR%20UAS%20Addendum%20(Version%201_0)%20-%20Final.pdf?ver=2019-12-13-144733-717

Table 53. Temporary Cellular Network Use Case.

Temporary Cellular Networks			
Location	Various	**Date**	Various
Drone	Various (Rotary)	**Type**	Support
Payload	Cellular UE, BSs, and relays		
Notes			
UAS are in the early stages of being able to carry both cellular UE and ground BS. This means that drones could serve as mobile, temporary sources of communication and network connection. In an emergency where communication has been severed, having a UAS to boost communication capabilities for responders could significantly improve the efficacy of the operation.			
Sources/References			
https://www.researchgate.net/publication/327496036_Survey_on_UAV_Cellular_Communications_Practical_Aspects_Standardization_Advancements_Regulation_and_Security_Challenges https://hal.science/hal-02786557			

Table 54. Tornado Response Use Case.

Tornado			
Location	Various	**Date**	June 12, 2017
Drone	Unknown (Rotary)	**Type**	Support
Payload	RGB and multi-spectral camera		
Notes			
Researchers looking into UAS response to tornado damage analyze three disaster scenarios and discuss how UAS could aid response efforts. While rotary UAS are commonly used for damage and cost analysis, the article explores how UAS mapping operations can record varying levels of vegetation damage in more rural areas. Using multispectral cameras to record high-resolution images, up to 2.5cm spatial resolution, evaluation of damage to both structure and vegetation in these communities can be more accurately ascertained to give a better understanding of the impact of tornados in previously underrepresented areas.			

Sources/References
https://journals.ametsoc.org/downloadpdf/view/journals/bams/100/12/bams-d-19-0124.1.pdf

2.1.4 Other Response Operations

Other response operations are not classified as natural, anthropogenic, or disaster response support operations. Other response operations may support disaster response and recovery but may do so indirectly. The following tables capture the use cases considered for this research.

Table 55. Evidence Collection Use Case.

Evidence Collection			
Location	Shrivenham, UK	**Date**	May, 2022
Drone	DJI SPARK, Other (Rotary)	**Type**	Other
Payload	1/2.3″ CMOS sensor		
Notes			
UAS are being tested to produce high-quality data for documenting and reconstructing outdoor forensic crime scenes. Using aerial photography, a crime scene can be simulated using data that is challenging to collect on the ground. Tests with drones detecting small foam rectangles as simulated objects on a crime scene showed higher accuracy in less time than a field team.			
Sources/References			
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9311223/			

Table 56. Internet of Things (IoT) and Artificial Intelligence (AI) Use Case.

IoT, AI, and the Future of UAS Autonomy			
Location	British Columbia, Canada	**Date**	Various
Drone	Unknown	**Type**	Other
Payload	Cellular UEs, BSs, and relays		
Notes			
The University of Management and Technology in Pakistan conducted research and experiments into how autonomous UAS can use IoT and AI in disaster response, specifically in Canadian wildfires. Focusing on ground IoT, communication technology, and data analytics, the benefits and challenges of designing a reliable IoT are explored. The research case study investigates an IoT network that can detect, monitor, and send notifications to affected people using the named data networking architecture. Highlighting cyber-security and the benefits of encryption and reduced latency.			

Infrastructure required: Ground sensor network, cellular-connected UASs assisted with IoT communication, and ground data analytics.
Sources/References
https://www.mdpi.com/1996-1073/12/14/2706

Table 57. Special Event Surveillance Use Case.

Special Events Surveillance			
Location	Glendale, AZ	**Date**	February 12, 2023
Drone	Unknown (Rotary)	**Type**	Other
Payload	RGB camera		
Notes			
During Super Bowl LVII, local law enforcement utilized multiple rotary UAS to secure and surveil the State Farm Stadium. This high-volume test supports future endeavors in the interest of security. A tether is useful for these long-lasting, semi-stationary missions.			
Sources/References			
https://www.pierceaerospace.net/blogs/news/pierce-aerospace-deploys-remote-id-to-super-bowl-57 https://www.faa.gov/superbowl/SBLVII-FA			

2.2 Sub-Task 3.2 – Characteristics and Requirements for Multi-UAS Operations

Operating multiple aircraft for disaster response and recovery operations, both manned and unmanned, allows responders to assess a disaster scene, allocate resources, and respond to meet mission objectives. While using multiple UAS and UAS alongside conventionally piloted assets offers some apparent advantages, such as data sharing, establishing area surveillance, mapping, and more, some challenges arise from sharing airspace. This section explores some challenges and possible solutions to the operation of multiple UAS and UAS alongside manned aircraft supporting disaster response and recovery operations.

Disaster response operations may involve a variety of air assets. According to a joint report by the National Air and Space Administration (NASA) and the Japan Aerospace Exploration Agency (JAXA), disaster response may involve air assets from multiple entities, such as firefighters, the military, media, and more (Andreeva-Mori et al., 2022). The variety of interests present at a disaster scene combined with the array of air assets likely in the air creates a need to manage and track air traffic to maintain safety. This is especially true as air assets in the airspace may be a mix of manned and unmanned aircraft. More importantly, a method for communicating amongst personnel and managing all the potential air traffic at a disaster scene must be localized to the area of need and scalable to suit the needs of responders while maintaining safety. Using Unmanned Traffic Management (UTM) systems for de-conflicting traffic, networks that enable communication and shared data, and systems that provide a Common Operating Picture (COP) to aid in integrating UAS and other air traffic may promote achieving safety and operational goals.

A key challenge in integrating multiple UAS and mixed air traffic for disaster response and recovery is the need to ensure the airspace is adequately deconflicted – i.e., the risk of collisions between aircraft in the airspace is acceptable for the nature of the mission.[1]. This is especially true as disaster response efforts may occur in relatively constrained environments with built-in hazards within the confines of a Temporary Flight Restriction.[2] (TFR). A Special Government Interest (SGI)[3] request may also define a constrained operations area. The need to deconflict airspace stems from the need to maintain safety while ensuring that responders can employ critical assets, such as helicopters, fixed-wing aircraft, and UAS, without posing additional risk to human life.

Subject matter experts on the research team noted the need to improve the SGI process to establish UAS areas quickly. Delays in establishing UAS operations areas through the SGI process have created challenges when deconflicting UAS from conventional aircraft and enabling responders to employ UAS. The SGI process should be reviewed to improve responders' ability to establish airspace boundaries to support their operations.

Joint research from NASA and JAXA offers promising solutions to managing low-altitude airspace for UAS in disaster response scenarios that could facilitate the operation of multiple UAS and UAS alongside conventional air assets. The solutions resulting from this research complement each other, building upon the established architecture for UTM (Figure 1) and integrating a networked solution for disaster response – Disaster Relief Aircraft Information Sharing Network (D-NET) (Figure 2).

[1] This assumes that disaster response and recovery missions carry some inherent risk above and beyond that of normal UAS flight operations – e.g., responding to an active forest fire. Some level of risk must be accepted on the part of the response team.
[2] https://www.faa.gov/air_traffic/publications/atpubs/foa_html/chap20_section_2.html
[3] There may be multiple requests by different agencies on scene. Timeliness and prioritization of requests may be challenging.

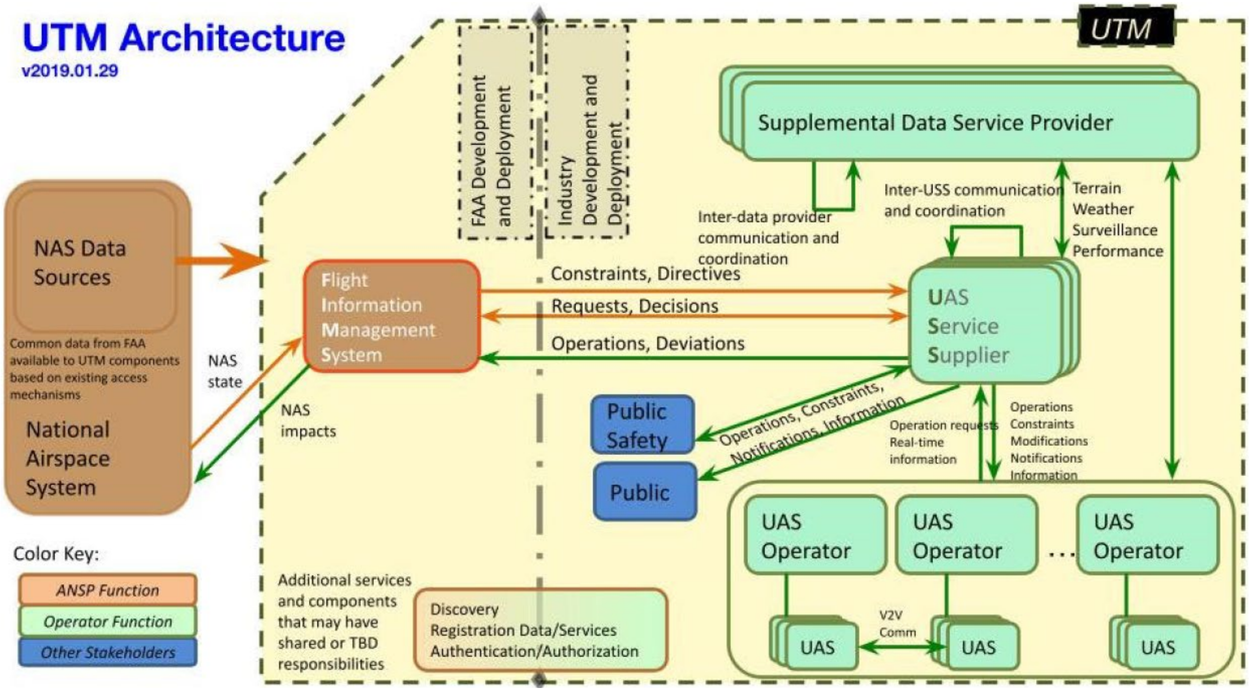

Figure 1. NASA UTM Architecture (Andreeva-Mori et al., 2022).

NASA's UTM architecture, as shown in Figure 1, offers the capability to provide flexible, scalable UAS operations while offering the ability to structure airspace as needed (Andreeva-Mori et al., 2022). The flexible nature of NASA's UTM architecture promotes airspace deconfliction, situational awareness, and coordination of aircraft, allowing responders to see and adapt to changes within the airspace while offering the capability to optimize UAS trajectories (Andreeva-Mori et al., 2022). UTM systems provide the flexibility to operate multiple UAS within a block of airspace and optimize trajectories to promote deconfliction. The system also facilitates connectivity with other systems, such as D-NET or another iteration of a COP. The application of UTM would promote the safe operation of multiple UAS while allowing situational awareness and providing the capacity to manage airspace to maintain safety for all airspace users on the scene.

D-NET, developed by JAXA, complements NASA's UTM architecture and offers unique functionality for disaster response. D-NET is a networked system that provides real-time data transmission and links between pilots, aircraft, and responders (Andreeva-Mori et al., 2022). D-NET consists of three primary "blocks" (Figure 2) and provides an efficient mechanism for sharing data across multiple platforms.

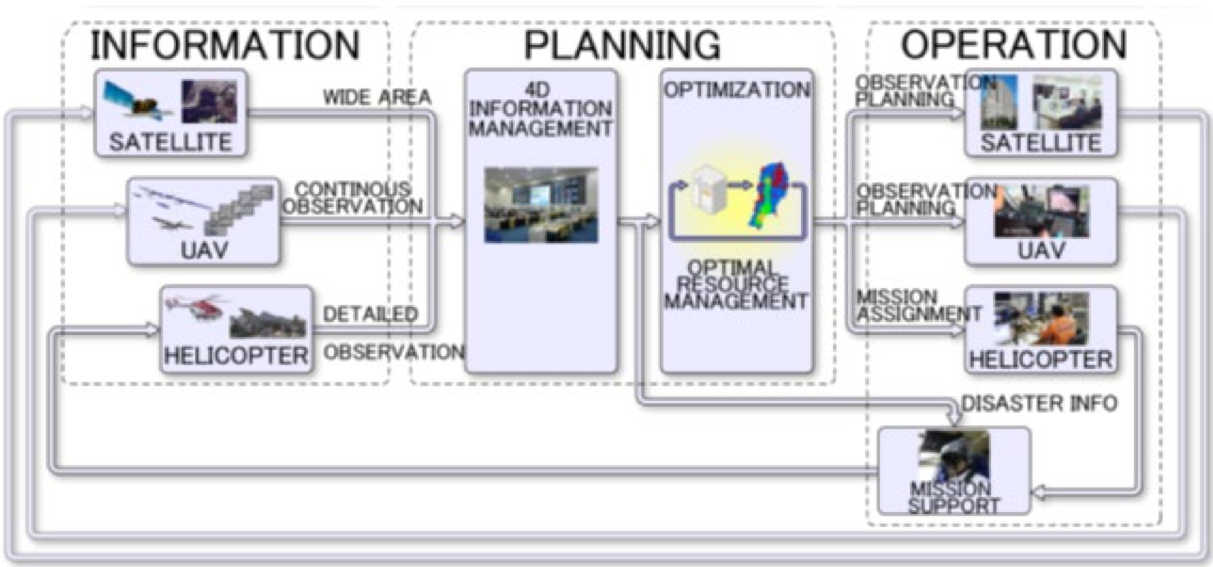

Figure 2. D-NET System Blocks and Operational Flow (Andreeva-Mori, 2022).

The benefit of D-NET is that it enables efficient use of resources and allocates aircraft based upon mission needs and equipage (Andreeva-Mori, 2022). Operations with multiple aircraft within a block of airspace could allow the sharing of crucial information – location, altitude, speed, and equipage. Such a system could aid in traffic deconfliction and enable coordination between multiple UAS and even conventionally piloted aircraft. Such a network may also allow broader connection for situational awareness tools, distilling data from wide-area, UAS, and conventional assets to manage operations on scene. More importantly, the information from a system like D-NET is fundamental to the function of COPs, as it provides a network for sharing critical operational data.

A COP combines fused situational awareness and planning tools to manage and direct multiple assets in real time. While a COP is not strictly used to prevent traffic conflicts between aircraft, it may offer safety benefits due to its ability to share information quickly. A COP provides a visualization of operations in a block of space – in both air and ground domains – with some measure of temporal accuracy. The data provided by a COP builds situational awareness while providing the capacity to share data across multiple assets and communicate in real-time, often without the need for a conventional radio. The result is increased capacity to manage complex operations via shared data and broad visibility of assets. A COP is a networked platform with a graphic user interface. A typical example of a COP, such as the Tactical Assault Kit (TAK), provides real-time information, video streams, live weather, and more (United States Government, 2024). An example of an integrated COP that links air and static ground assets is shown in Figure 3. This example integration of a COP was used to validate the use of such a system for first responders as part of this research.

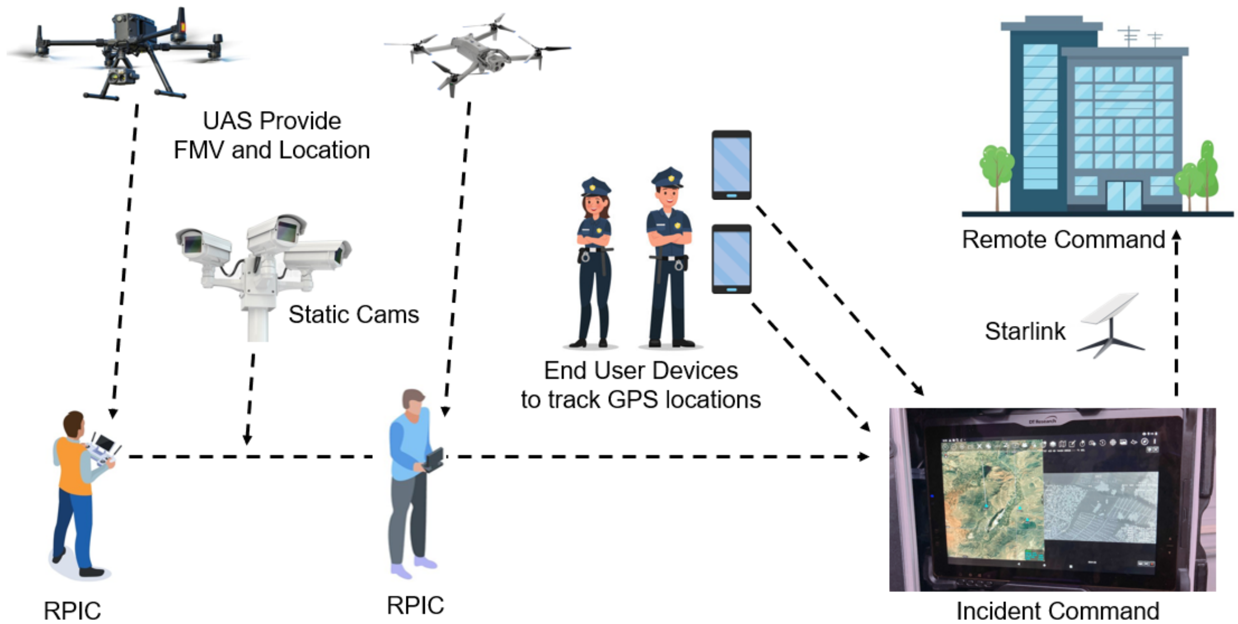

Figure 3. Example Common Operating Picture (COP) integration with TAK.

The benefit of a COP resides in its ability to share data quickly across all assets. More importantly, it offers the ability to see where each asset is in real time and direct resources where they are needed. Added situational awareness provides a layer of safety alongside a greater capacity to allocate resources on the scene.

The practical applications for UTM, network infrastructure like D-NET, and a COP are that they enable communication to occur that enables multi-UAS operations within a disaster area. These systems provide essential communication and data exchange for responders. Fusing communications from multiple aircraft, location information, and sensor data allows critical personnel, such as an air boss, to coordinate with an incident commander to manage air assets on the scene. This allows an air boss to segregate UAS from each other and other air traffic. These tools also enable responders to allocate UAS resources where needed and communicate across all assets to ensure mission effectiveness.

Operating multiple UAS and operating UAS alongside manned aircraft for disaster response and recovery offer numerous challenges, the biggest being airspace deconfliction and situational awareness. These things are critical as multiple entities may have UAS and conventional air assets operating on the scene. This enhances the need for communication and data sharing to maintain safety. UTM architecture and networked systems for sharing data, like D-NET and COPs, offer avenues to operate multiple UAS safely at disaster scenes. They also provide responders with the tools necessary to share critical information quickly, allowing them to maintain safety and allocate resources effectively.

2.3 Sub-Task 3.3 – Additional Use Cases for Health and Pandemic Response

UAS applications in healthcare and pandemic relief operations were identified well before the most recent SARS-COV-2, or COVID-19, ranging from pharmaceutical deliveries, critical hospital logistics, triage assessments, and mass casualty events (Thiels et al., 2015). However, that global disruption coincided with significant technological advancement integrating UAS into hazard mitigation planning for natural and manmade hazards, improved network communications, and advanced Concepts of Operations (CONOPS), such as operations of multiple UAS or swarms (Lawson and Rajan, 2023). The FAA introduced new rules and regulations for UAS operations in the National Airspace System (NAS) during the COVID-19 pandemic that, according to FAA Administrator Steve Dickson, "…gets us closer to the day when we will more routinely see drone operations such as the delivery of packages" (Federal Aviation Administration, 2020). These new rules included the requirement for remote identification of UAS to enhance airspace awareness and reduce the risk of UAS interference with other aircraft, people, and property on the ground. Accelerated interest in healthcare applications of UAS and regulatory guidance to address complex operational use cases have illustrated other policy implications for safety, security, and privacy for routine UAS operations in communities worldwide, such as medical delivery (Martins, Lavallée, & Silkoset, 2021). In general, UAS applications in pandemic relief revolve around four main functions: (1) Sanitization/Disinfection, (2) Healthcare Logistics, (3) Social Monitoring/Surveillance, and (4) Communications. These functions are further broken down across the spectrum of public safety mission sets, such as reconnaissance of health, crowd control, public safety announcements, medicine delivery, testing/sample transportation, aerial spraying, and contactless delivery (Kramer, n.d.).

2.3.1 Sanitation and Disinfection

Sanitation with UAS employs a similar CONOPS as agricultural spraying, where aircraft are equipped with liquid cleaning agents dispersed in open-air public areas to reduce the spread of infection. The general notion is that UAS offers an effective platform for larger-scale, more consistent disinfection of open-air public areas by flying programmed flight paths for spraying. Aerial spraying is often accompanied by public announcements via flyers or loudspeakers to notify people of disinfection activities (Euchi, 2021). There is a challenge for spray disinfection to reach all areas of a surface due to large holes or gaps, such as with building surfaces or porous building material. Ultra-Violet (UV) disinfection is another common medical practice. Still, it may not apply to UAS due to the requirement to illuminate the area for several minutes for effective disinfection and how close the UV sensor must be to the surface.

2.3.2 Healthcare Logistics

The healthcare supply chain becomes rapidly strained in pandemic situations. UAS provides a means to alleviate the increased demand on logistics to deliver life-saving supplies such as testing kits, vaccinations, personal protective equipment, blood and other transfusions, and other cargo as necessary. Using UAS and other robotics for medical delivery reduces human interaction for contactless delivery in clinic and pharmacy settings, making the technology a potentially effective means to reduce infection spread between people. Demonstrations for UAS delivery also show considerable promise to streamline the supply chain by reducing reliance on ground transportation.

These advantages include quicker delivery times, decreased road congestion, increased accessibility to rural communities, and potentially reduced consumer costs when proper infrastructure is in place. Rapid delivery of samples and tests within a medical district or mall between testing centers and laboratories may lead to more effective monitoring of infection spread and safer practices for medical professionals. In addition to reduced supply chain strains, the "chain of survival" for individuals experiencing life-threatening conditions, such as cardiac arrests, is also a prominent application for UAS delivery of life-saving tools, such as Automated External Defibrillators (AED) (Zègre-Hemsey et al., 2024). The rapid delivery of AEDs via UAS for cardiac arrest outside of a hospital offers a greater chance of survival compared to conventional ambulance response (Schierbeck et al., 2023).

2.3.3 Social Monitoring and Surveillance

Crowd tracking and screening for symptoms of illness during pandemic relief efforts is an effective means to monitor the spread of infection in populated areas. Remote screening methods involve contactless thermometers and other tools to estimate skin temperature, respiratory rate, heart rate, and other indicators of illness. UAS equipped with thermal Infrared (IR) sensors has demonstrated the ability to estimate skin temperature and detect coughing and sneezing in crowds. There are still challenges in the reliability of these estimates using conventional UAS equipped with IR sensors. Still, the specialization of cameras for this application is under development for use cases in pandemic relief (Gupta & Goel, 2021). Crowd tracking and symptom monitoring amongst groups using UAS sensors may help differentiate febrile individuals from healthy ones and collect data points for infection spread.

2.3.4 Communication

Maintaining communication during pandemic relief operations is an essential task by emergency personnel to help avoid concern among the general public. Broadcasting public safety announcements and warnings via UAS offers a unique means to deliver messages in communities during quarantines or in dense crowds. One-way speaker attachments for UAS are relatively common for public safety agencies performing law enforcement duties or urban search and rescue to help communicate to victims that they have been spotted and emergency assistance is in the area. Similar to manned aerial advertisement, UAS equipped with flags or boards with Quick Response (QR) codes have been used in communities to provide public relief details or contact information.

2.4 Sub-Task 3.4 – Optimal Characteristics of UAS for Disaster Preparedness

When assessing the characteristics of the optimum UAS(s) for disaster preparedness, it comes down to the specific application. The desired flight profiles, transmission of information, sensors used, flight time needed, function, and more dictate the best tool for the application. Tables 58, 59, 60, and 61 highlight disasters by category – e.g., natural disaster, anthropogenic disaster, etc., and outline the optimal UAS and sensors for identified use cases. There are endless combinations of specific UAS that can be used with particular sensors. The tables also provide a breakdown of event types and required functions. These functions include Mapping, Live Feed, Sensor, Delivery, and Comms. Most support functions fit into these broad categories. These tables address the research question of which types of UAS to support which use cases. Each of these 50+ cases could be further expanded from the baseline elements presented to formulate optimum characteristics for each disaster type.

2.4.1 Summary Tables

Table 58. Events, UAS, Sensor(s), and Functions for Natural Disasters.

Natural Disasters							
Event	**UAS**	**Sensor(s)**	**Function**				
			Mapping	**Live Feed**	**Sensor**	**Delivery**	**Comms**
Avalanche	Unknown (Rotary)	Thermal and RGB		X			
Biological Incidents	Rotary or Fixed-Wing	Thermal and RGB	X	X			
Dust Storm	3DR Solo (Rotary)	Pressure Sensor and RGB		X	X		
Drought	DJI M600 Pro UAS (Rotary)	Multispectral and Thermal	X				
Flooding	Various Rotary and Fixed-Wing	RGB	X	X		X	
Heatwave	Unknown (Rotary)	Infrared and RGB	X				
Landslide	AirRobot AR100B (Rotary), Insitu Scan Eagle (Fixed-Wing), and PrecisionHawk Lancaster (Fixed-Wing)	LIDAR and Thermal	X				
Lava Flow	DJI Mavic 2 Pro quadcopter and Custom hexacopter	Multispectral, Radiometric Thermal, and RGB	X	X			
Microburst	Rotary	LIDAR, Thermal, RGB	X	X			
Monitoring Invasive Species	DJI Matrice 600 (Rotary)	Spectroscopic	X				

Tsunami	DJI Phantom 2 vision plus (Rotary)	RGB	X				
Wildfire	Various (Rotary, VTOL)	Thermal and RGB	X	X			

Table 59. Events, UAS, Sensor(s), and Functions for Anthropogenic Disasters.

Anthropogenic Disasters							
Event	**UAS**	**Sensor(s)**	**Function**				
			Mapping	**Live Feed**	**Sensor**	**Delivery**	**Comms**
Animal, Agriculture, and Food Disaster	X8 octocopter (Rotary) and custom FX79 airframe (Fixed-Wing)	RGB	X				
Bombing Incidents	Rotary	LIDAR, Infrared, and RGB	X	X			
Bridge Inspection	Various (Rotary)	Thermal and RGB	X	X			
Building Collapse	Various (Rotary)	Thermal and RGB	X	X			
Crowd Control	Rotary	RGB	X	X			
Culverts Under Roads	Rotary	LIDAR and RGB	X	X			
Dam Inspection/Erosion	Unknown (Rotary)	RGB	X				
Dam and Levee Security	Rotary or Fixed-Wing	Moisture, LIDAR, Thermal, and RGB	X	X	X		
Debris Management	Unknown (Rotary)	Thermal and RGB	X				
Deforestation Monitoring	Unknown (Fixed-Wing)	LIDAR and RGB	X				
Highway Disaster	DJI Inspire 1, Phantom 3, and Various Other (Rotary)	RGB	X				

Hospital Radiology Emergency	Rotary	Radiation Sensor and Thermal		X	X		
Marine Pollution	Honeywell T-Hawk (Rotary) and Custom (Fixed-Wing)	Radiation Sensor and RGB	X				
Nuclear EMS	Various (Rotary and VTOL Fixed-Wing)	Polarimetric and RGB	X	X	X		
Oil & Hazardous Substance Pollution	Rotary and Fixed-Wing	Optical Gas Imaging and Infrared	X	X			
Pipeline Leak	Various (Rotary)	Thermal, Infrared, and RGB	X	X			
Plane/Helicopter Crash	DJI Phantom 2 Vision Plus (Rotary) and DJI Inspire Pro (Rotary)	RGB	X	X			
Shipwreck	Phantom4 quadcopter and Unknown (Rotary)	RGB	X				
Site Protection (Crime Scene Preservation)	Rotary	RGB		X			
Subsidence	Feima D2000 (Rotary)	LIDAR and RGB	X				
Tank Car Disaster	Rotary	Gas Detection, Infrared	X		X		
Water Contamination/Pollution	Unknown (Rotary)	Infrared	X				
Water and Wastewater Utilities	Rotary	Specialized Sensors	X				

Table 60. Events, UAS, Sensor(s), and Functions for Disaster and Emergency Response Support Operations.

Disaster and Emergency Response Support Operations							
Event	**UAS**	**Sensor(s)**	**Function**				
			Mapping	**Live Feed**	**Sensor**	**Delivery**	**Comms**
Cave Rescue	Unknown (Rotary)	Thermal, Night-Capable, and RGB	X	X			
Coastal Hazard	Unknown	RGB	X				
Debris Management Plan Development	Rotary or Fixed-Wing	LIDAR, Thermal, RGB	X	X			
Emergency Medical Delivery/ Community Resilience	Custom (Fixed-Wing)	Geolocation				X	
Facility	Rotary	Gas Detection, Thermal, RGB	X	X	X		
Hazardous Gas	Custom (Rotary)	Vibration and Gas Sensors			X		
Lifelines, Logistics, and Supply Chain	Rotary or Fixed-Wing	RGB	X	X			
Mass Antibiotics Dispensing	Rotary or Fixed-Wing	RGB		X		X	
Mass Fatalities	Rotary	Thermal and RGB	X	X			
Mitigation for Tribal Governments	Rotary	Cellular UEs, BSs, and Relays					X
Offshore Safety and Emergency Response	Unknown (Rotary)	Thermal and RGB	X				
Population Security/Counter Terrorism	Rotary	RGB	X	X			

Post-Earthquake Internal Building Inspection	Flyability Elios 3 (Rotary)	RGB	X	X			
Power Line Inspection	Unknown (Rotary)	RGB		X			
Space Weather	Various (Rotary)	Cellular UEs, BSs, and Relays	X				X
Support for People	Rotary	Thermal and RGB	X	X			
Swarm Search and Rescue	Unknown (Fixed Wing, Rotary)	Infrared, Multispectral, EO, and Lidar	X	X			
Temporary Cell Network	Various (Rotary)	Cellular UEs, BSs, and Relays					X
Tornado	Unknown (Rotary)	RGB and Multispectral	X				

Table 61. Events, UAS, Sensor(s), and Functions for Other Response Operations.

Other Response Operations							
Event	**UAS**	**Sensor(s)**	**Function**				
			Mapping	**Live Feed**	**Sensor**	**Delivery**	**Comms**
Evidence Collection	DJI SPARK, Other (Rotary)	1/2.3″ CMOS Sensor	X				
IoT, AI, and the Future of UAS Autonomy	Unknown	Cellular UEs, BSs, and Relays	X				X
Special Events Surveillance	Unknown (Rotary)	RGB		X			

2.4.2 Cyber Vulnerabilities

An additional element to assess related to disaster response is cyber vulnerability within the UAS support mission lifecycle. ASSURE Task A38 (and other ASSURE efforts) have looked at potential cyber vulnerabilities based on attack types and mapped these to the phases of UAS operations. The phases of operation include the following:

- Pre-Flight/Mission Planning,
- Preparation/System Checks,
- Launch,
- Mission/Application/Flight,
- Return to Land,
- Post Flight, and
- Others.

A graphic of these UAS Phases of Operation from the ASSURE A38 research is shown in Figure 5 with types of attacks presented in Table 62. Risks can be assessed based on severity and likelihood using a typical 5x5 risk matrix (Figure 4).

Likelihood \ Severity	Minimal 5	Minor 4	Major 3	Hazardous 2	Catastrophic 1
Frequent A	Low	Medium	High	High	High
Probable B	Low	Medium	High	High	High
Remote C	Low	Medium	Medium	High	High
Extremely Remote D	Low	Low	Medium	Medium	High
Extremely Improbable E	Low	Low	Low	Medium	High* / Medium

Figure 4. Typical 5x5 Risk Matrix

Tables showing the likelihood (Table 63) and severity (Table 64) are presented, as well as the final estimated risk (Table 65). While this may not be germane to specific UAS use cases, it does point to potential support issues when UAS may be used in disaster response. There are vulnerabilities in the planning and preparation stages. Most of the vulnerabilities are in the flight and return to land phases. All use cases should have a planning element that assesses what could go wrong if bad actors try to disrupt operations. This may be a potential in emergency situations. These cyber vulnerabilities are included here to raise understanding and promote planning for critical UAS operations.

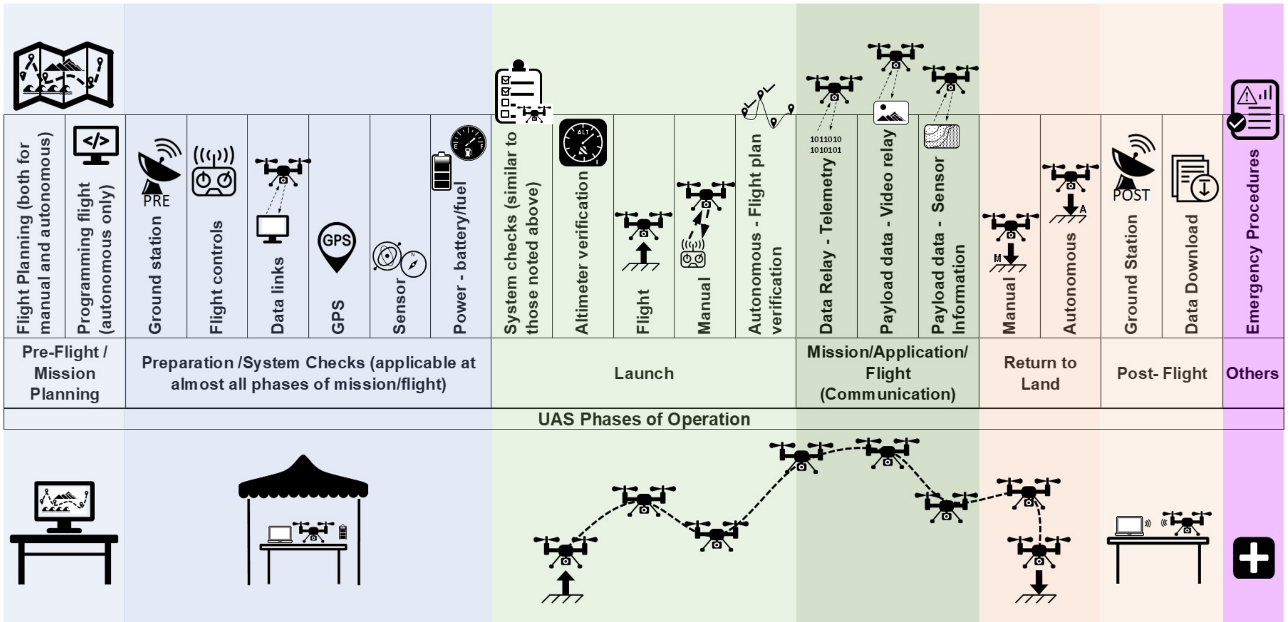

Figure 5. Phases of Operation.

Table 62. Types of Cyber Attacks.

Attack Reference Number	Attack Reference Number	Top Category	Method of Attack
NLx	NL-ID	**Network Link**	
NL1	NL-BH/GH	**Network Link**	Black Hole/Gray Hole
NL2	NL-W	**Network Link**	Wormhole
NL3	NL-Syb	**Network Link**	Sybil
NL4	NL-Sink	**Network Link**	Sinkhole
NL6	NL-PBJam	**Network Link**	Protocol-based Jamming (Message Flooding)
NL7	NL-D	**Network Link**	Deauthentication
NL8	NL-PS/A	**Network Link**	Packet Sniffing/Analysis
NL9	NL-PB	**Network Link**	Password Breaking
NL10	NL-PiM	**Network Link**	Person-In-The-Middle
NL11	NL-CJ	**Network Link**	Command Injection
NL12	NL-M	**Network Link**	Masquerading
NL13	NL-ReplayA	**Network Link**	Replay Attack
NL14	NL-RelayA	**Network Link**	Relay Attack
NL15	NL-F	**Network Link**	Fuzzing
SWx	SW-ID	**Software**	
SW1	SW-CI	**Software**	Code Injection
SW2	SW-DI	**Software**	Database Injection
SW3	SW-FM	**Software**	Firmware Modification
SW4	SW-SD	**Software**	Sleep Deprivation
SW5	SW-BO	**Software**	Buffer Overflow
SW6	SW-MI	**Software**	Malware Infection
SW7	SW-SCA	**Software**	Supply Chain Attack

Attack Reference Number	Attack Reference Number	Top Category	Method of Attack
HWx	**HW-ID**	**Hardware**	
HW1	HW-S/GPS	**Hardware**	Spoofing - GPS
HW2	HW-S/OS	**Hardware**	Spoofing - Other Sensors
HW3	HW-S/ADSB-ID	**Hardware**	Spoofing - ADS-B, Remote ID
HW4	HW-S/A	**Hardware**	Spoofing - Actuator
HW5	HW-J/GPS	**Hardware**	Jamming - GPS
HW6	HW-J/OS	**Hardware**	Jamming - Other Sensors
HW7	HW-J/ADSB-ID	**Hardware**	Jamming - ADS-B, Remote ID
HW8	HW-J/A	**Hardware**	Jamming - Actuator
HW9	HW-FF	**Hardware**	Firmware Flashing
HW10	HW-SCA	**Hardware**	Supply Chain Attack
GCSx	**GCS-ID**	**GCS**	
GCS1	GCS-RA	**GCS**	Remote Access
GCS2	GCS-RQA	**GCS**	Forced Quitting Application
GCS3	GCS-DE	**GCS**	Data Exfiltration
GCS4	GCS-PB	**GCS**	Password Breaking
GCS5	GCS-RE	**GCS**	Reverse Engineering GCS Application/Software
GCS6	GCS-SE	**GCS**	Social Engineering
SRVx	**SRV-ID**	**Server**	
SRV1	SRV-DL	Server	Data Leakage
SRV2	SRV-PIL	Server	Pilot Identity Leakage
SRV3	SRV-LL	Server	Location Leakage

Table 63. Cyber Attack Assessed Likelihood.

		UAS Phases of Operation																				
		Pre-Flight / Mission Planning		Preparation /System Checks (applicable at almost all phases of mission/flight)						Launch					Mission/Application/Flight (Communication)			Return to Land		Post- Flight		Others
Attack Reference Designation	Likelihood Legend: Frequent (A) (Probability) ≥ 1 per 1,000 Probable (B) 1 per 1000 > (Probability) ≥ 1 per 100,000 Remote (C) 1 per 100,000 > (Probability) ≥ 1 per 10,000,000 Extremely Remote (D) 1 per 10,000,000 > (Probability) ≥ 1 per 1,000,000,000 Extremely Improbable (E) 1 per 1,000,000,000 > (Probability) ≥ 1 per 10^14	Flight Planning (both for manual and autonomous)	Programming flight (autonomous only)	Ground station	Flight controls	Data links	GPS	Sensor	Power - battery/fuel	System checks (similar to those noted above)	Altimeter verification	Flight	Manual	Autonomous - Flight plan verification	Data Relay - Telemetry	Payload data - Video relay	Payload data - Sensor Information	Manual	Autonomous	Ground Station	Data Download	Emergency Procedures
NL-ID	**Network Link Attack**																					
NL-BH/GH	Black Hole/Gray Hole	E	E	E	E	E	E	E	E	B	C	C	C	C	C	C	C	C	C	E	E	B
NL-W	Wormhole	E	E	E	E	E	E	E	E	D	D	D	D	D	C	C	C	C	C	E	E	B
NL-Syb	Sybil	E	E	E	E	E	E	E	E	C	D	C	D	D	D	D	D	D	D	E	E	D
NL-Sink	Sinkhole	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
NL-RFJam	Radio Frequency (RF)-based Jamming	E	E	E	E	E	E	E	E	D	D	D	D	D	C	C	C	A	A	E	E	A
NL-PBJam	Protocol-based Jamming (Message Flooding)	E	E	E	E	E	E	E	E	C	C	C	C	C	A	A	A	C	C	E	E	A
NL-D	Deauthentication	E	E	E	E	E	E	E	E	A	A	A	B	A	A	A	A	B	A	A	A	B
NL-PS/A	Packet Sniffing/Analysis	E	E	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
NL-PB	Password Breaking	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
NL-PiM	Person-In-The-Middle	E	E	E	E	E	E	E	E	E	E	C	C	D	A	A	A	A	A	E	E	A
NL-CJ	Command Injection	E	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	A	A
NL-M	Masquerading	E	E	E	E	E	E	E	E	E	E	E	E	E	B	B	B	C	C	B	B	B
NL-ReplayA	Replay Attack	E	E	E	E	E	E	E	E	A	A	A	B	A	A	A	A	E	E	E	E	A
NL-RelayA	Relay Attack	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
NL-F	Fuzzing	E	E	E	E	E	E	E	E	A	A	A	B	A	A	A	A	B	A	A	A	A
SW-ID	**Software Attack**																					
SW-CI	Code Injection	A	A	A	A	A	A	A	A	D	E	E	E	E	E	E	E	E	E	E	E	E
SW-DI	Database Injection	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
SW-FM	Firmware Modification	A	A	A	A	A	A	A	A	D	D	D	D	D	D	D	D	D	D	A	A	D
SW-SD	Battery Draining	E	E	E	E	E	E	E	E	E	D	D	D	D	D	D	D	D	D	E	E	D
SW-BO	Buffer Overflow	E	E	E	E	E	E	E	E	A	D	D	D	D	D	B	B	D	D	A	A	E
SW-MI	Malware infection	A	A	A	A	A	A	A	B	B	A	A	A	A	A	A	B	A	A	A	A	A
SW-SCA	Supply Chain Attack	E	E	A	B	C	A	A	A	B	A	A	A	A	C	C	D	A	A	C	D	A
HW-ID	**Hardware Attack**																					
HW-S/GPS	Spoofing - GPS	E	E	D	A	A	A	A	C	D	A	A	B	B	A	A	A	A	A	D	D	A
HW-S/OS	Spoofing - Other Sensors	E	E	D	A	A	A	A	C	D	A	A	B	B	A	A	A	A	A	D	D	A
HW-S/ADSB-ID	Spoofing - ADS-B, Remote ID	D	D	C	C	C	C	C	C	A	A	A	A	A	A	A	A	B	B	C	C	A
HW-S/A	Spoofing - Actuator	E	E	D	A	A	A	A	C	D	A	A	B	B	A	A	A	A	A	D	D	A
HW-J/GPS	Jamming - GPS	E	E	E	A	A	A	A	C	D	A	A	A	B	A	A	A	A	A	E	E	A
HW-J/OS	Jamming - Other Sensors	E	E	E	A	A	A	A	C	D	A	A	A	B	A	A	A	A	A	E	E	A
HW-J/ADSB-ID	Jamming - ADS-B, Remote ID	D	D	C	C	C	C	C	C	A	A	A	A	A	A	A	A	B	B	C	C	A
HW-J/A	Jamming - Actuator	E	E	E	A	A	A	A	C	D	A	A	A	B	A	A	A	A	A	E	E	A
HW-FF	Firmware Flashing	B	A	B	B	B	B	B	B	C	C	C	C	C	C	C	C	C	C	C	C	C
HW-SCA	Supply Chain Attack	E	E	A	B	C	A	A	A	B	A	A	A	A	C	C	D	A	A	C	D	A
GCS-ID	**Ground Control System (GCS) Attack**																					
GCS-RA	Remote access	C	C	D	C	B	C	C	D	C	C	C	C	C	B	B	B	A	A	D	D	A
GCS-RQA	Forced quitting application	C	C	D	C	B	C	C	D	C	C	C	C	C	B	B	B	A	A	D	D	A
GCS-DE	Data exfiltration	D	D	B	B	B	D	D	E	A	B	B	B	B	A	A	A	A	A	A	A	A
GCS-PB	Password Breaking	D	D	A	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	A	D	A
GCS-RE	Reverse Engineering GCS Application/Software	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	C	C	D
GCS-SE	Social Engineering	A	A	A	A	A	A	A	A	D	D	D	A	B	A	A	A	D	D	E	E	B
SRV-ID	**Server Attack**																					
SRV-DL	Data leakage	C	B	A	A	A	C	C	D	B	B	B	B	B	A	A	A	A	A	A	A	A
SRV-PIL	Pilot identity leakage	A	A	A	E	E	E	E	E	E	E	C	E	E	E	E	E	E	E	A	B	D
SRV-LL	Location leakage	A	A	A	E	E	E	E	E	D	E	B	D	B	E	E	E	A	A	A	C	C

Table 64. Cyber Attack Assessed Severity.

		UAS Phases of Operation: Pre-Flight / Mission Planning		Preparation /System Checks (applicable at almost all phases of mission/flight)						Launch					Mission/Application/Flight (Communication)			Return to Land		Post- Flight		Others
Attack Reference Number	**Severity Legend:** 5: Minimal 4: Minor 3: Major 2: Hazardous 1: Catastrophic	Flight Planning (both for manual and autonomous)	Programming flight (autonomous only)	Ground station	Flight controls	Data links	GPS	Sensor	Power - battery/fuel	System checks (similar to those noted above)	Altimeter verification	Flight	Manual	Autonomous - Flight plan verification	Data Relay - Telemetry	Payload data - Video relay	Payload data - Sensor Information	Manual	Autonomous	Ground Station	Data Download	Emergency Procedures
NL-ID	**Network Link Attack**																					
NL-BH/GH	Black Hole/Gray Hole	5	5	5	5	5	5	5	5	5	4	1	1	1	5	5	5	1	1	5	5	1
NL-W	Wormhole	5	5	5	5	5	5	5	5	5	3	1	1	1	5	5	5	1	1	5	5	1
NL-Syb	Sybil	5	5	5	5	5	5	5	5	5	3	3	3	3	5	5	5	2	2	5	5	2
NL-Sink	Sinkhole	5	5	5	5	5	5	5	5	2	2	1	1	1	4	3	3	1	1	3	3	1
NL-RFJam	Radio Frequency (RF)-based Jamming	5	5	5	5	5	5	5	5	5	5	1	1	1	5	5	5	1	1	5	5	1
NL-PBJam	Protocol-based Jamming (Message Flooding)	5	5	5	5	5	5	5	5	5	5	1	1	1	5	5	5	1	1	5	5	1
NL-D	Deauthentication	5	5	4	4	4	4	4	5	4	4	3	3	3	5	5	5	1	1	5	5	1
NL-PS/A	Packet Sniffing/Analysis	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
NL-PB	Password Breaking	5	5	1	5	5	5	5	5	3	5	1	1	1	5	5	5	1	1	5	5	1
NL-PiM	Person-In-The-Middle	5	5	5	5	5	5	5	5	5	5	1	1	1	5	5	5	1	1	5	5	5
NL-CJ	Command Injection	5	5	5	5	5	5	5	5	3	5	1	1	1	5	5	5	1	1	5	5	1
NL-M	Masquerading	5	5	4	4	4	4	4	5	4	4	3	3	3	5	5	5	1	1	5	5	2
NL-ReplayA	Replay Attack	5	5	5	5	5	5	5	5	5	5	1	1	1	5	5	5	1	1	5	5	1
NL-RelayA	Relay Attack	5	5	5	5	5	5	5	5	5	5	1	1	1	5	5	5	1	1	5	5	1
NL-F	Fuzzing	5	5	5	5	5	5	5	5	5	5	1	1	1	5	5	5	1	1	5	5	1
SW-ID	**Software Attack**																					
SW-CI	Code Injection	5	5	5	5	5	5	5	5	1	1	1	1	1	5	5	5	1	1	5	5	1
SW-DI	Database Injection	5	5	5	5	5	5	5	5	1	1	1	1	1	5	5	5	1	1	5	5	1
SW-FM	Firmware Modification	5	5	5	5	5	5	5	5	2	3	1	1	1	5	5	5	1	1	5	5	1
SW-SD	Sleep Deprivation	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	4
SW-BO	Buffer Overflow	5	5	5	5	5	5	5	5	5	5	1	1	1	5	5	5	1	1	5	5	2
SW-MI	Malware infection	4	4	4	4	4	4	3	2	2	3	3	3	3	4	4	4	1	1	3	4	1
SW-SCA	Supply Chain Attack	5	5	5	5	5	5	5	5	5	5	1	1	1	5	5	5	1	1	5	5	2
HW-ID	**Hardware Attack**																					
HW-S/GPS	Spoofing - GPS	5	5	5	5	5	5	5	5	2	1	1	1	1	5	5	5	1	1	5	5	1
HW-S/OS	Spoofing - Other Sensors	5	5	5	5	5	5	5	5	2	1	1	1	1	5	5	5	1	1	5	5	1
HW-S/ADSB-ID	Spoofing - ADS-B, Remote ID	5	5	5	5	5	5	5	5	4	4	4	4	4	5	5	5	4	4	4	4	4
HW-S/A	Spoofing - Actuator	5	5	5	5	5	5	5	5	2	1	1	1	1	5	5	5	1	1	5	5	1
HW-J/GPS	Jamming - GPS	5	5	5	5	5	5	5	5	1	1	1	1	1	5	5	5	1	1	5	5	1
HW-J/OS	Jamming - Other Sensors	5	5	5	5	5	5	5	5	1	1	1	1	1	5	5	5	1	1	5	5	1
HW-J/ADSB-ID	Jamming - ADS-B, Remote ID	5	5	5	5	5	5	5	5	4	4	4	4	4	5	5	5	4	4	4	4	4
HW-J/A	Jamming - Actuator	5	5	5	5	5	5	5	5	1	1	1	1	1	5	5	5	1	1	5	5	1
HW-FF	Firmware Flashing	4	4	4	4	4	4	3	2	2	3	3	3	3	4	4	4	1	1	3	4	1
HW-SCA	Supply Chain Attack	5	5	5	5	5	5	5	5	5	5	1	1	1	5	5	5	1	1	5	5	2
GCS-ID	**Ground Control System (GCS) Attack**																					
GCS-RA	Remote access	5	5	5	5	5	5	5	5	5	5	3	3	3	5	5	5	3	3	5	5	3
GCS-RQA	Forced quitting application	5	5	2	2	2	3	2	2	1	1	1	1	1	5	5	3	1	1	5	5	1
GCS-DE	Data exfiltration	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
GCS-PB	Password Breaking	5	5	5	5	5	5	5	5	5	5	3	3	3	5	5	5	3	3	5	5	1
GCS-RE	Reverse Engineering GCS Application/Software	5	5	5	5	5	5	5	5	5	5	3	3	3	5	5	5	3	3	5	5	1
GCS-SE	Social Engineering	5	5	5	5	5	5	5	5	5	5	3	3	3	5	5	5	3	3	5	5	1
SRV-ID	**Server Attack**																					
SRV-DL	Data leakage	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
SRV-PIL	Pilot identity leakage	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
SRV-LL	Location leakage	5	5	5	5	5	3	3	4	3	3	3	3	3	5	5	5	3	3	5	5	3

Table 65. Cyber Attack Assessed Risk.

		UAS Phases of Operation																				
		Pre-Flight / Mission Planning		Preparation /System Checks (applicable at almost all phases of mission/flight)						Launch					Mission/Application/Flight (Communication)			Return to Land		Post- Flight		Others
Attack Reference Number	**Severity vs. Likelihood Legend:** Low (L) - Green Medium (M) - Yellow High/Medium (H/M) - Pink High (H) - Red	Flight Planning (both for manual and autonomous)	Programming flight (autonomous only)	Ground station	Flight controls	Data links	GPS	Sensor	Power - battery/fuel	System checks (similar to those noted above)	Altimeter verification	Flight	Manual	Autonomous - Flight plan verification	Data Relay - Telemetry	Payload data - Video relay	Payload data - Sensor Information	Manual	Autonomous	Ground Station	Data Download	Emergency Procedures
NL-ID	**Network Link Attack**																					
NL-BH/GH	Black Hole/Gray Hole	L	L	L	L	L	L	L	L	L	M	H	H	H	L	L	L	H	H	L	L	H
NL-W	Wormhole	L	L	L	L	L	L	L	L	L	M	H	H	H	L	L	L	H	H	L	L	H
NL-Syb	Sybil	L	L	L	L	L	L	L	L	L	M	M	M	M	L	L	L	M	M	L	L	M
NL-Sink	Sinkhole	L	L	L	L	L	L	L	L	M	M	*H/M	*H/M	*H/M	L	L	L	*H/M	*H/M	L	L	*H/M
NL-RFJam	Radio Frequency (RF)-based Jamming	L	L	L	L	L	L	L	L	L	L	H	H	H	L	L	L	H	H	L	L	H
NL-PBJam	Protocol-based Jamming (Message Flooding)	L	L	L	L	L	L	L	L	L	L	H	H	H	L	L	L	H	H	L	L	H
NL-D	Deauthentication	L	L	L	L	L	L	L	L	M	M	H	H	H	L	L	L	H	H	L	L	H
NL-PS/A	Packet Sniffing/Analysis	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
NL-PB	Password Breaking	L	L	H	L	L	L	L	L	H	L	H	H	H	L	L	L	H	H	L	L	H
NL-PiM	Person-In-The-Middle	L	L	L	L	L	L	L	L	L	L	H	H	H	L	L	L	H	H	L	L	L
NL-CJ	Command Injection	L	L	L	L	L	L	L	L	M	L	H	H	H	L	L	L	H	H	L	L	H
NL-M	Masquerading	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	H	H	L	L	H
NL-ReplayA	Replay Attack	L	L	L	L	L	L	L	L	L	L	H	H	H	L	L	L	*H/M	*H/M	L	L	H
NL-RelayA	Relay Attack	L	L	L	L	L	L	L	L	L	L	*H/M	*H/M	*H/M	L	L	L	*H/M	*H/M	L	L	*H/M
NL-F	Fuzzing	L	L	L	L	L	L	L	L	L	L	H	H	H	L	L	L	H	H	L	L	H
SW-ID	**Software Attack**																					
SW-CI	Code Injection	L	L	L	L	L	L	L	L	H	*H/M	*H/M	*H/M	*H/M	L	L	L	*H/M	*H/M	L	L	*H/M
SW-DI	Database Injection	L	L	L	L	L	L	L	L	H	H	H	H	H	L	L	L	H	H	L	L	H
SW-FM	Firmware Modification	L	L	L	L	L	L	L	L	M	M	H	H	H	L	L	L	H	H	L	L	H
SW-SD	Sleep Deprivation	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
SW-BO	Buffer Overflow	L	L	L	L	L	L	L	L	L	L	H	H	H	L	L	L	H	H	L	L	M
SW-MI	Malware infection	M	M	M	M	M	M	H	H	H	H	H	H	H	M	M	M	H	H	H	M	H
SW-SCA	Supply Chain Attack	L	L	L	L	L	L	L	L	L	L	H	H	H	L	L	L	H	H	L	L	H
HW-ID	**Hardware Attack**																					
HW-S/GPS	Spoofing - GPS	L	L	L	L	L	L	L	L	M	H	H	H	H	L	L	L	H	H	L	L	H
HW-S/OS	Spoofing - Other Sensors	L	L	L	L	L	L	L	L	M	H	H	H	H	L	L	L	H	H	L	L	H
HW-S/ADSB-ID	Spoofing - ADS-B, Remote ID	L	L	L	L	L	L	L	L	M	M	M	M	M	L	L	L	M	M	M	M	M
HW-S/A	Spoofing - Actuator	L	L	L	L	L	L	L	L	M	H	H	H	H	L	L	L	H	H	L	L	H
HW-J/GPS	Jamming - GPS	L	L	L	L	L	L	L	L	H	H	H	H	H	L	L	L	H	H	L	L	H
HW-J/OS	Jamming - Other Sensors	L	L	L	L	L	L	L	L	H	H	H	H	H	L	L	L	H	H	L	L	H
HW-J/ADSB-ID	Jamming - ADS-B, Remote ID	L	L	L	L	L	L	L	L	M	M	M	M	M	L	L	L	M	M	M	M	M
HW-J/A	Jamming - Actuator	L	L	L	L	L	L	L	L	H	H	H	H	H	L	L	L	H	H	L	L	H
HW-FF	Firmware Flashing	M	M	M	M	M	M	H	H	H	M	M	M	M	M	M	M	H	H	M	M	H
HW-SCA	Supply Chain Attack	L	L	L	L	L	L	L	L	L	L	H	H	H	L	L	L	H	H	L	L	H
GCS-ID	**Ground Control System (GCS) Attack**																					
GCS-RA	Remote access	L	L	L	L	L	L	L	L	L	L	M	M	M	L	L	L	H	H	L	L	H
GCS-RQA	Forced quitting application	L	L	M	H	H	M	H	M	H	H	H	H	H	L	L	H	H	H	L	L	H
GCS-DE	Data exfiltration	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
GCS-PB	Password Breaking	L	L	L	L	L	L	L	L	L	L	M	M	M	L	L	L	M	M	L	L	H
GCS-RE	Reverse Engineering GCS Application/Software	L	L	L	L	L	L	L	L	L	L	H	H	H	L	L	L	H	H	L	L	H
GCS-SE	Social Engineering	L	L	L	L	L	L	L	L	L	L	M	H	H	L	L	L	M	M	L	L	H
SRV-ID	**Server Attack**																					
SRV-DL	Data leakage	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
SRV-PIL	Pilot identity leakage	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
SRV-LL	Location leakage	L	L	L	L	L	L	L	L	M	L	H	M	H	L	L	L	H	H	L	L	M

2.5 Sub-Task 3.5 – Lessons Learned from Previous Demonstrations

Lessons from previous use case demonstrations are captured in the ASSURE A52 lessons learned report – *A52: Disaster Preparedness and Response II – Lessons Learned*. This report addresses the following research questions within the scope of weather-related disasters, pandemic response, train derailments, and wildfire response use cases:

1. What subset of use cases for the different disaster preparedness and response efforts are representative to demonstrate that UAS can help facilitate response?
2. How did the various agencies, responders, participants, and support personnel coordinate in the demonstrations and the lessons learned to ensure safe operations after a disaster?
3. What are the common risks for the use cases, and what are the mitigations to those risks to ensure safe operations for UAS?
4. What are the CONOPS and Operational Risk Analysis for the specific use cases identified?
5. What category of vehicles will work with each mission type?
6. What are the characteristics of the optimum UAS(s) for disaster preparedness?
7. What should future coordination with FEMA/DOI/DHS look like with UAS integrated into the NAS?
8. What are the considerations for secure Command and Control links?
9. What are the cyber security considerations?
10. What recommendations can be made for the refinement of requirements, technical standards, policies, procedures, guidelines and regulations needed to enable emergency response operations for use cases using UAS that increase effective, efficient, and safe use of UAS in a disaster?

Lessons learned are summarized according to their applicability to selected use cases within the ASSURE A52 lessons learned report. The report offers key findings for each use case, makes specific recommendations, and links findings to applicable research questions.

2.6 Sub-Task 3.6 – When UAS May Not Be Optimal for Disaster Response

The application of UAS in disaster and emergency scenarios is based on the suitability of a given UAS for a given mission set. However, there are situations in which the employment of UAS for disaster response and recovery may not be optimal. The following represent general conditions in which the use of UAS for disaster response and recovery may not be beneficial:

1. Weather conditions may make the employment of UAS unsafe or impractical,
2. Performance limitations of the UAS cannot perform as desired to meet mission objectives, and
3. Societal considerations that may limit operations.

The following sections explore these limitations when identifying cases when deploying a UAS would not be optimal for disaster response and recovery.

2.6.1 Weather Conditions

Certain conditions may make using UAS for disaster response and recovery unsafe. These conditions may be rooted in the nature of the disaster itself and other factors. One of the most significant limitations on the employment of UAS is weather.

The weather may drastically impact the ability to safely employ a UAS for disaster response and recovery. Weather limitations beyond the baseline within 14 CFR §107.51 may significantly affect the ability to operate UAS. UAS, particularly small Unmanned Aircraft Systems (sUAS), are more susceptible to wind, rain, snow, ice, and temperature extremes. When environmental factors such as these preclude the safe and effective use of UAS, other air assets, such as conventional airplanes and helicopters, may be more effective and safer. This is especially true when weather conditions may make controlling an Unmanned Aircraft (UA) difficult or when compliance with regulations is challenging – i.e., excessive wind or updrafts make the UA hard to control, or smoke makes it difficult to maintain line-of-sight. Similarly, extreme temperatures may have a deleterious effect on UAS batteries. Freezing temperatures may drastically reduce flight times. Excessively hot temperatures may also damage UAS batteries and significantly impact flight performance.

Mitigating the risks associated with weather combines knowing the limits of the UAS and the knowledge and training of remote pilots. Hazardous weather conditions may not necessarily preclude UAS operations if the UAS is designed to operate in those conditions, and remote pilots can operate the aircraft safely while maintaining compliance with applicable regulations. However, when these conditions cannot be met, UAS should not be employed.

2.6.2 UAS Performance Limitations

In some cases, performance limitations of the UAS themselves may limit their utility for disaster response and recovery. UAS come in various types and configurations, as shown in Table 66. While Table 66 does not include all possible UAS configurations, it addresses some of the most common and provides generic performance assessments. All these different UAS have their strengths and weaknesses, whether it be limitations on endurance, requiring a prepared operating area, or payload size. The implication is that the employment of a UAS requires the "right tool for the right job," and it follows that not every UAS is suitable for the same mission or environment. For example, a multirotor UAS has less endurance than a fixed-wing asset. Therefore, a multirotor is not optimal for long-duration surveillance of a disaster area. Similarly, a multirotor UAS may be useful for navigating in and around structures or a collapsed building, while a fixed-wing UAS is less than optimal for that task. In short, deploying a UAS for disaster response and recovery depends highly on the aircraft available to responders and its performance characteristics concerning the mission. Considerations such as payload size, time on station, support equipment/launch recovery operations, and other mission requirements must be considered.

Table 66. UAS Types and Limitations

UAS Type	Example Platform	General Characteristics
Fixed-Wing		• Typically requires a prepared surface for takeoff/landing. • Longer endurance; between 8 – 20 hours depending on fuel source – i.e., electric vs internal combustion. • Ideal use case(s): long-duration ISR, SAR, and mapping.
Hybrid Fixed-Wing		• Requires a smaller takeoff/landing area due to VTOL characteristics; can operate better in austere environments. • Significant endurance: 8 – 15 hours, depending on the power system. • Ideal use case(s): long-duration ISR, SAR, and mapping.
Conventional Rotorcraft[4]		• Requires a smaller takeoff/landing area than fixed-wing counterparts. • Moderate endurance; flight times may exceed 1 hour.

[4] Image from Aerovironment - https://www.instagram.com/p/B-pu0IAFJt-/

		• Ability to reliably hover and employ sensors. • Ideal use case(s): ISR and SAR over moderately large areas where endurance greater than a multirotor may be required.
Multirotor		• Requires minimal area for takeoff and landing. • Can be deployed very quickly. • Very limited endurance; Approximately 45 minutes. • Limited sensor/payload capabilities relative to size. • Ideal use case(s): SAR in localized areas.

With all these considerations in mind, there may be instances when deploying a UAS is not ideal because the limitations of the UAS themselves are not commensurate with the needs of the mission. In some cases, certain types of UAS may be better to fulfill specific mission objectives. Other times, deploying conventional air assets may offer certain advantages due to the need for larger payloads, larger aircraft, or other factors that may render UAS risky or impractical.

In short, choosing to employ UAS for a given mission comes down to choosing the right tool for the right job. In making this decision, one must consider mission requirements, available assets – UAS and conventional aircraft – regulatory considerations, and overall mission safety. There may be instances when using a UAS does not offer the advantages it may otherwise provide. Similarly, there may be instances when the UAS responders have at their disposal may not be ideal for the mission. The decision to employ UAS for disaster response and recovery must consider the performance of the UAS, its mission, operational safety, and the practicality associated with using all available assets.

2.6.3 Societal and Cultural Considerations

There are instances where societal and cultural concerns may make the employment of UAS for disaster response impractical. These issues may stem from legal structures, societal expectations, and other societal norms. There may also be unique cultural concerns that may hamper or prevent the use of UAS for disaster response and recovery.

2.6.3.1 *Societal Considerations*

One example of a societal issue that may arise for responders is the issue of property rights. Subject matter experts from the A62 research team identified occasions where ideal takeoff and landing locations were on private property. These takeoff and landing locations were ideal for satisfying the operational requirements and maintaining safety. However, responders could not obtain landowners' permission to use their property for UAS operations, so these sites were not used. This is just one example, but it highlights one of the more significant challenges facing responders when attempting to establish UAS operations on scene.

Similarly, responders may grapple with privacy concerns when operating UAS, various sensors, and radio frequency devices within and around communities. The concept of privacy, particularly near private property and urban and suburban communities, is a common concern that may persist even as UAS becomes commonplace for disaster response, law enforcement, and other first-response roles.

2.6.3.2 *Cultural Considerations*

One consideration for not using UAS relates to community and cultural sensitivities. This can include physical sites, traditions, and possibly questions of tribal sovereignty. There is a diversity within Native American communities. There are over 500 federally recognized tribes in the United States, each with distinct language, customs, and traditions. Some locations are considered sacred to different cultures. Often, these sacred sites and closed access areas are among the most important to the religious exercise of Indigenous peoples.

Culturally, there may be physical locations or sites that are off-limits, have restricted access, or have restrictions on taking photographs (and, by extension, video and data collection). These sites are all over the world. These areas may or may not be designated or marked for people outside their local communities. A physical site may be within the desired UAS operational area during a disaster or emergency.

Cultural sensitivity is not just limited to physical locations but also the exercise of active traditions. Many communities close off sections of their lands during celebrations, ceremonies, and other culturally sensitive events. An area may be open to the public and have no restrictions during much of the year but be blocked and private for specific periods. It may not be the physical site that presents the cultural sensitivity concerns, but the events themselves, including vestments, actions, aural elements (spoken, sung, music, etc.), personnel, etc. Timing and the nature of the restrictions may not be easily obtainable public information.

Some locations or areas are only identified to the local user community. Some locations are more widely known. An example of an international location is restrictions on photography in places like Uluru-Kata Tjuta National Park in the Northern Territory, Australia. (Uluru was previously known as Ayres Rock). The ancient aboriginal tribe from Uluru-Kata Tjuta Park observes their rituals with sanctity and restricts visitors from taking photographs or making documentaries. The Valley of the Kings in Luxor, Egypt, is also off-limits to photography. While photography and video are not the same as a drone flight, these elements present questions before a flight, with the addition of any other associated data gathering.

While not germane to cultural sensitivity specifically, there are other locations where it may not be optimal to operate UAS if photos or video are obtained and, by extension, other data. There are restrictions inside many buildings. One cannot take pictures inside the Alamo, Las Vegas casinos, or the Pentagon; there are even guidelines for taking pictures inside all US Post Offices. Photos of the Eifel Tower are not legally allowed to be published. This could present potential issues for UAS response in the area surrounding this iconic monument.

A UAS operator must know whose land they are on and whom to contact. While it may be legal to fly from a US Federal Government approval standpoint, it may not be appropriate due to local considerations of site, ceremony, or tribal sovereignty. With a broader view, UAS operations may have potential with local approval. The guidance provided by many communities is to "Always ask permission first – act later." This is where contacting a liaison from the impacted communities is essential. It may be a challenge to provide timely actional information in emergencies. Including this information in advanced planning, contact generation, and coordination can help address concerns before events.

2.7 Sub-Task 3.7 – Safety Risks and Mitigations Associated with UAS for Disaster Response and Recovery

Every UAS operation incurs risk, and these unique risks may be identified, assessed, and mitigated. This section addresses the risks and safety measures associated with UAS in disaster response and the risks involved in implementing the proposed mitigation(s). The information provided leverages content prepared from the ASSURE A28 research effort and adds new risk elements. Each risk is listed and organized into four categories – operations, equipment, aircraft, and personnel. The risks identified within these categories are as follows:

<u>Operations</u>

- Positioning of launch and recovery areas
- Severe weather*
- Temporary Airspace restriction*
- Toxic ash/gasses*
- Weather and forecasts

<u>Equipment</u>

- Aircraft maintenance
- Lack of landing over water*
- Matching flight assets to response – area sensors, time, etc.
- Natural Disaster increases in intensity*

Aircraft

- Deployment checklists
- Mission checklists
- Refueling*
- Loss of power*
- Tethered fly-away*
- Payload Bay*
- Loss of power and data transfer to tethered UAS*
- Tether breaks*
- Loss of Telemetry
- Unable to stay airborne or Takes Too Long to Launch*
- Taken out of service*

Personnel

- Common language
- Crew Fatigue*
- Lack of Contact with Flight Service for Notice to Airmen (NOTAM)
- Unsafe operations over people/property*
- Line-of-Sight (LOS)*
- Confliction of frequencies
- Loss of Communication*
- Time synchronization (multiple aircraft) *

All items with an asterisk (*) above have their "Risk" and "Mitigation" sections derived from the "A28 Common Concept of Operations" documents. These were all defined by disaster type. There was considerable repetition in that document, which is not duplicated here. Absent from that report was an assessment of the "Risks of Implementing Mitigation." The "Risks of Implementing Mitigation" were added for the previously identified risks. All new risks identified were formatted in the same way. Under each hazard is the explanation of the risk, the proposed mitigation, the risks related to the resulting recommendations, and a list of disasters associated with the hazard

("Risk," "Mitigation," "Risks of Implementing Mitigation," and "Applicable Disasters"). A list of all hazards in their respective categories is below.

2.7.1 Operations

The following sub-sections represent factors affecting risks and mitigations associated with UAS operations. While the risks and associated mitigations listed here are not exhaustive, they represent a reasonable cross-section of factors that responders must consider. These risks and their associated mitigations resulted from input from this research and past work from ASSURE A28.

2.7.1.1 *Positioning of launch and recovery areas:*

Risk: This hazard results from improper positioning of takeoff and landing areas because of difficulties due to a disaster. Unsafe conditions include debris, unstable ground, nearby people, or smoke. Results can include damage to the aircraft, property, or injury.

Mitigation: The Remote Pilot In Command (RPIC) and flight crew must assess the proposed launch and recovery area before the mission. This process can include a list of hazards to look for and requirements the area must meet to be deemed safe. The RPIC will also designate a secondary launch and landing area to be used if the primary one encounters the effects of the disaster. The RPIC and flight crew must also stay in constant contact about the condition of the primary area.

Risks of Implementing Mitigation: Some possible risks of this mitigation could be related to dynamic disaster conditions, time constraints, and human factors. If a disaster scenario changes rapidly, a primary and secondary designated launch and recovery area may no longer be suitable. Time constraints mean that designating launch areas could result in more harm than launching without regard to launch and landing areas. Fatigue and stress could also mean that those assessing launch and recovery areas may not evaluate them accurately and may also demonstrate a preference for areas nearby.

Applicable Disasters:

- Airport terrorism
- Earthquake and Tsunami
- Hurricane, Tornado, and Flooding
- Oil Spill
- Pandemic - LUAS (Large UAS)
- Pandemic - sUAS (Small UAS)
- Train Derailment
- Volcano
- Wildfire

2.7.1.2 *Severe Weather*

Risk: This hazard results from changing atmospheric conditions, so there is a no-go for flight operations. Possible effects are a stop in flight operations and an aircraft that must rapidly Return to Land (RTL) or end the flight, and the team left waiting and unable to complete their mission.

Mitigation: During the flight, if weather conditions deteriorate suddenly, the RPIC assesses if Divert Land Immediately (DLI) is required or if they can invoke Return to Base (RTB), resulting in a suspension of the onward flight path. DLI will ensure the flight lands safely and close to the original location. If the RPIC can determine that the flight can still operate with the RTB in place, then the UAS will follow this pattern, i.e., its launch/landing point. Given the weather conditions, the mission will use the defined landing zones developed in the CONOPS to divert and land immediately if continued safe flight becomes impossible. Suppose multiple UAS flights occur simultaneously and are in the same airspace, supporting a disaster response. In that case, pre-mission coordination on each flight's alternative landing zones must occur to mitigate any mid-air collisions from DLI or RTB flights.

Risks of Implementing Mitigation: In severe winds, rain, or other precipitation-related weather events, it may be unsafe to enact DLI or RTB flights, especially if operating over people. Ground crews may experience challenges coordinating multiple landing zones for emergency landings, which could result in loss of UAS or pose safety risks to ground crew.

Applicable Disasters:

- Airport terrorism
- Earthquake and Tsunami
- Hurricane, Tornado, and Flooding
- Oil Spill
- Pandemic - LUAS
- Pandemic - sUAS
- Train Derailment
- Volcano
- Wildfire

2.7.1.3 *Temporary Airspace Restrictions*

Risk: Large UAS will start at a local airport and fly in the NAS and the specific airspace at and surrounding this airport. It will then fly from the NAS, where there could be other crewed and uncrewed systems, into a Temporary Flight Restriction (TFR) set up over the disaster site. The flight team does not have permissions established with the operations center and will be unable to enter TFR.

Mitigation: The flight crew and RPIC coordinate with the operations center and air boss for emergency response so that they are always aware of the location of the large UAS. The RPIC and flight mission lead will set up all permissions before any missions start to ensure that the large UAS can respond to all needs and enter and leave the TFR when needed.

Risks of Implementing Mitigation: The main risk to the proposed mitigation is that the UAS team could work under tense time constraints. Despite attempts to establish a connection before a mission, if too much time is required to request any relevant permission, the UAS cannot assist in disaster response.

Applicable Disasters:

- Airport terrorism
- Earthquake and Tsunami
- Hurricane, Tornado, and Flooding
- Volcano
- Wildfire

2.7.1.4 *Toxic ash/gasses*

Risk: This hazard caused by toxic material concentrations impacting the aircraft and visibility leads to Instrument Flight Rules only conditions. Possible effects resulting from this hazard are a loss of aircraft performance and ability to continue the mission.

Mitigation: The RPIC will perform controlled flight operations to remove the aircraft from the toxic levels. The RPIC will assess if the levels in the atmosphere limit the ability of the UAS to operate and the crew to continue to operate. The RPIC will determine if an RTB or RTL is required or if the aircraft can continue operations. The mission RPIC will invoke a DLI, which suspends the onward flight path and commands the UAS to land at a designated landing zone in a controlled manner at the maximum safe descent rate.

Risks of Implementing Mitigation: Navigational errors could occur due to the changing ash level and limited visibility in the air. If operating simultaneously with other UAS, an RTB maneuver may lead to mid-air collisions with other UAS due to potentially limited visibility.

Applicable Disasters:

- Oil Spill
- Volcano
- Wildfire

2.7.1.5 *Weather and Forecasts*

Risk: Lack of weather forecasts can mean that UAS operations could encounter unexpected weather patterns such as wind, light rain, or fog. This could impair the operation by obstructing onboard cameras, shorting electronics, or impairing sensor ability. The side effects of not checking weather forecasts could be landing prematurely, losing LOS, or the RPIC losing control of the UAS.

Mitigation: This could be prevented by checking weather forecasts well in advance and ensuring that the most up-to-date weather data is obtained. If weather forecast observations are not conducted beforehand, then real-time mitigations could include utilizing other similar UAS that are more suited to variable weather or modifying the current UAS to be more weather resistant.

Risks of Implementing Mitigation: Inaccurate weather forecasts could mean UAS operations can be surprised by rain or high winds. Suppose weather forecasts are not consulted before operating in remote areas. In that case, internet-based forecasts may not be available due to limited reception, meaning UAS might encounter weather conditions unsuitable for safe operation.

Applicable Disasters:

- Airport terrorism
- Earthquake and Tsunami
- Hurricane, Tornado, and Flooding
- Oil Spill
- Pandemic - LUAS
- Pandemic - sUAS
- Train Derailment
- Volcano
- Wildfire

2.7.2 Equipment

The following sub-sections represent factors affecting risks and mitigations associated with UAS equipment. While the risks and associated mitigations listed here are not exhaustive, they represent a reasonable cross-section of risk factors that responders must consider. These risks and their associated mitigations resulted from input from this research and past work from ASSURE A28.

2.7.2.1 *Aircraft Maintenance*

Risk: Improper UAS maintenance could result in faulty components such as motors, gyroscopes, or the landing gear. A fault in these could pose a severe danger to the crew if a flight is attempted with faulty components on board. Unsafe motors and props could mean that the UAS pitches towards the flight crew, similar to a gyroscope being impaired. A landing gear that does not deploy may result in excessive damage to the UAS.

Mitigation: Before a flight, a pre-flight checklist should be conducted to ensure the quality of all components onboard the UAS, and if this checklist is not passed, then the UAS should stay grounded. Regular maintenance should be conducted to ensure that the UAS remains airworthy.

Risks of Implementing Mitigation: Outdated checklists would cause confusion when inspecting the UAS if modifications have been made since the checklist was constructed. If a checklist is being consulted in an emergency scenario, the maintenance crew may rush through the checklist improperly, which could lead to safety risks.

Applicable Disasters:

- Airport terrorism
- Earthquake and Tsunami
- Hurricane, Tornado, and Flooding
- Oil Spill
- Pandemic - LUAS
- Pandemic - sUAS
- Train Derailment
- Volcano
- Wildfire

2.7.2.2 *Lack of Landing Over Water*

Risk: This hazard comes from a small UAS flying over water, the crew's failure to define a safe landing zone, and the inability to perform a manual landing back on the boat. Possible effects are the sUAS having to ditch into the water as it does not have a safe landing site or fails to land back onto the boat.

Mitigation: Before the mission, the RPIC of the sUAS will determine a range of potential landing locations if there is an issue with the aircraft as it flies over the water or if the visual observer cannot track it. Zones on land will be defined as alternates for the boat landing site used for the disaster analysis. All backup landing sites will be chosen to ensure a safe landing, and the aircraft can land away from any water. If the only option is to land on water, the RPIC and flight crew will use RTB to ensure a reusable UAS and, if impossible, instigate a safe DLI procedure.

Risks of Implementing Mitigation: Backup landing sites may become inaccessible during the flight of the UAS, forcing the RPIC to initiate an RTB or lose the UAS. When performing an RTB maneuver, the UAS may lose the GPS signal or communication with the RPIC, possibly resulting in a loss of the UAS.

Applicable Disasters:

- Hurricane, Tornado, and Flooding
- Oil Spill

2.7.2.3 *Matching Flight Assets to Response – Area Sensors, Time, Etc.*

Risk: Due to the uniqueness of each disaster, generalization of response procedures could lead to severe oversight of potential risks. Ensuring the proper equipment is present and deployed at the scene is critical for mission success. Failure to do so could result in delayed response or elevated risk to the responding team.

Mitigation: Before the flight, the RPIC and their team will conduct thorough research and planning into the type of disaster and all available information regarding the disaster in question. This will include communication with those who have been to the disaster site and those on the response team. A list of required tasks and associated assets will be drafted from this. A well-thought-out flight plan and activity schedule will be created before the response effort and strictly adhered to. While on-site, the RPIC will communicate with the rest of the team about ongoing safety risks.

Risks of Implementing Mitigation: Poor communication could result in improper flight assets for a specific disaster scenario, wasting time and resources. If unique flight assets are determined to be required for a disaster response operation, the UAS team may not have access to these assets, meaning that the team will not be able to complete their tasks.

Applicable Disasters:

- Airport terrorism
- Earthquake and Tsunami
- Hurricane, Tornado, and Flooding
- Oil Spill
- Pandemic - LUAS
- Pandemic - sUAS
- Train Derailment
- Volcano
- Wildfire

2.7.2.4 *Natural Disaster Increases in Intensity*

Risk: This hazard results from a rapid change in the activity that puts the responding team at risk. Possible effects include evacuating the flight team and aircraft at risk during the disaster response mission.

Mitigation: During this flight, the RPIC will ensure that the UAS captures the data needed for the disaster response. For volcanic activity, the RPIC will work with their flight crew to be informed on the future plume and cloud dispersal as well as an increase in volcano color code and seismic signals so that they can be prepared to manually fly the aircraft to locations where the observations needed can be collected and evacuate their area to find a new, safe site for operations as well as takeoff and landing. If this requires Visual Line-Of-Sight (VLOS) operations, the crew will review if the permissions are in place to support this type of mission before proceeding. Similar communication between RPIC and crew will be maintained for other disasters, such as wildfires and earthquakes, to identify indications of future events or ongoing changes so the crew can adequately react to the situation.

Risks of Implementing Mitigation: Natural disasters could create harsh conditions, such as wind, rain, or air-borne particulates, which would lead to UAS malfunction or failure and reduce the safety and operational integrity of the mission. Low-quality communication between the RPIC and ground crew could lead to a delay or faulty decision-making concerning crew safety.

Applicable Disasters:

- Earthquake and Tsunami
- Hurricane, Tornado, and Flooding
- Wildfire
- Volcano

2.7.3 Aircraft

The following sub-sections represent factors affecting risks and mitigations associated with UA and related procedures. While the risks and associated mitigations listed here are not exhaustive, they represent a reasonable cross-section of factors that responders must consider. These risks and their associated mitigations resulted from input from this research and past work from ASSURE A28.

2.7.3.1 *Deployment Checklists*

Risk: Responding to a disaster, the pressure of the event could cause the RPIC and team to rush operations for time-sensitive or ongoing disasters. This can lead to several failures that prolong or potentially halt response efforts. Improper deployment of UAS could lead to runaway events, inflight failure, and increased risk to team members and responders. It is necessary to take precautions before arrival to mitigate forgetfulness amongst the distractions of a disaster.

Mitigation: Each UAS should have a deployment checklist that is unique to it. These checklists should highlight potential areas of failure and mechanisms essential to a successful flight. These should include physical inspection of wings, blades, and other features on the UAS to ensure there is no damage and they are fit to fly. Payloads, including batteries and cameras, should be inspected to ensure they are charged, working as intended, and adequately secured to the UAS. All communication and telemetry to the UAS and crew should be validated before launch. Finally, the air and ground around the launchpad should be free from debris or other aircraft. The checklist should be completed and dated before launch.

Risks of Implementing Mitigation: In time-sensitive scenarios, maintenance personnel performing checklists may skip checklist items, intentionally or not. This could mean that an unsatisfactory UAS is launched, potentially leading to harm during takeoff, flight, or landing to the UAS or surrounding team. If checklists are poorly designed or outdated, a similar scenario may occur.

Applicable Disasters:

- Airport terrorism
- Earthquake and Tsunami
- Hurricane, Tornado, and Flooding
- Oil Spill
- Pandemic - LUAS
- Pandemic - sUAS
- Train Derailment
- Volcano
- Wildfire

2.7.3.2 *Mission Checklists*

Risk: While responding to a disaster, all team members must follow a strict mission plan to ensure that the response is carried out promptly and correctly. Failure to adhere to the mission could lead to conflicting operations being performed simultaneously or an incomplete response. This can lead to equipment malfunctions, compromised safety, and data loss, which could cause significant backend issues or failure of the overall mission.

Mitigation: Proper diligence will be exercised before response to ensure the appropriate operations are completed. This would involve a meeting to discuss the mission objective, site assessment, required equipment, flight plan, weather conditions, and regulatory compliance. Each of these elements is essential and will be included in the checklist. Understanding the operating location and weather and planning around potential risks will reduce the unforeseen challenges in the field. Also, having the meeting to discuss the disaster will allow for the correct UAS operations to be performed. Ensuring regulations are followed, and appropriate on-site equipment is available will enable the mission to be performed as intended. All participants will review necessary checklists and adherence to these checklists will be monitored throughout the operation.

Risks of Implementing Mitigation: If a disaster requires an emergency response, the team may not have time to conduct a meeting to establish the mission objective and related information. This means the team may not be on the same page, leading to poor communication, confusion, and safety risks. Despite planning around potential risks, unexpected conditions may always arise, forcing the team to reconsider their plan regarding the mission.

Applicable Disasters:

- Airport terrorism

- Earthquake and Tsunami
- Hurricane, Tornado, and Flooding
- Oil Spill
- Pandemic - LUAS
- Pandemic - sUAS
- Train Derailment
- Volcano
- Wildfire

2.7.3.3 *Refueling*

Risk: This hazard comes from a large UAS performing multiple or prolonged flights and having enough fuel/power to complete the flights and all operations needed to remove the supplies. Possible effects are the large UAS being unable to complete the two flights and having to return to the original take-off location. The lack of fuel could lead to a loss of capability to control the UAS and a controlled or uncontrolled descent into terrain/terrestrial entities.

Mitigation: The mission team will leave at least a predetermined amount (ex., 30 minutes or 1 hour) of reserve fuel on board throughout the flight profile. The mission team will ensure that the flight checklists include details on population density and communities along their flight route. Alternative landing sites will be identified so the RPIC can manually fly the UAS to the new landing zone. Alternatively, the aircraft can be assigned to a new landing site if automated flight is still possible and safe. Multiple UAS flights may occur simultaneously and in the same airspace, supporting disaster response; pre-mission coordination on each flight's alternative landing zones must occur to mitigate any mid-air collisions from DLI or RTB flights.

Risks of Implementing Mitigation: Fuel consumption rates may exceed predictions, reducing the expected operational time of the UAS. If multiple UAS are in the air simultaneously, landing sites may become occupied, leading to extended flight times and increased fuel consumption while waiting for landing sites to become available.

Applicable Disasters:

- Airport terrorism
- Pandemic Case LUAS

2.7.3.4 *Loss of Power*

Risk: This hazard comes from losing power and control of a large UAS, providing higher altitude surveillance on the response operation. Possible effects are the loss of high-altitude surveillance data, an inoperable airborne communications hub, and an RTB or uncontrolled descent of the UAS.

Mitigation: Mitigation would include assigning ditch points for the UAS in the CONOPS so the team is prepared for safe landings if unable to return home. The crew member responsible for mission team safety and the ground control station will inform the RPIC or mission manager of the loss of power. Depending on UAS capabilities, reaching a prescribed ditch point during a power loss may not be possible. However, if the UAS can reach the ditch point, these points should be monitored for pedestrian/ground traffic to ensure a safe landing is possible. Visual Observers (VO) in place for VLOS operations will support the RPIC in understanding any risks on the ground below the aircraft's location when power is lost. Multiple UAS flights may occur simultaneously and in the same airspace, supporting disaster response; pre-mission coordination on each flight's alternative landing zones must occur to mitigate any mid-air collisions from DLI or RTB flights.

Risks of Implementing Mitigation: Navigational errors could occur due to the vehicle's limited control during power issues, increasing the risk of inaccurate flight to designated ditch points. If multiple UAS operate simultaneously, RTB or DLI maneuvers may lead to mid-air collisions due to potentially limited situational awareness and communication among the different flight teams.

Applicable Disasters:

- Earthquake and Tsunami
- Hurricane, Tornado, and Flooding
- Oil Spill
- Pandemic Case LUAS
- Train Derailment LUAS

2.7.3.5 *Tethered Fly-Away*

Risk: The tethered UAS will be secured at a fixed altitude. It will be positioned close to people and property. The tether could break, putting the UAS in fly-away mode.

Mitigation: The flight crew will have an RPIC even with the UAS fixed to the building and in a fixed location. If the tether breaks, this RPIC would take over manual operations for the UAS, return it to the fixed location, and hover to ensure continued operations. The RPIC will communicate with operations personnel to determine when to land the UAS to fix the tether and resume normal operation. The tether should be fixed if possible. If not, UAS could be flown manually to a predetermined location to provide necessary observations.

Risks of Implementing Mitigation: Human errors could be a factor during manual operation, especially in hazardous environments. Manual control could lead to difficulty in accurate positioning, increasing the risk of collisions with nearby structures or people. If other UAS are operating in the area, manual flight could increase the likelihood of mid-air collisions due to limited reaction time and situational awareness.

Applicable Disasters:

- Airport terrorism

- Train Derailment
- Wildfire

2.7.3.6 *Payload Bay*

Risk: This hazard arises from the ground crew at the second site being unable to offload the supplies and access the payload bay. Possible effects are a failure to drop off the supplies at the needed location and a return to the original take-off site within completing the mission.

Mitigation: The ground team at each site will be trained to access the payload bay for the small UAS and will have communications with the two PICs at the Ground Control Station (GCS) and the flight teams. Depending on the mission type, the ground team can be part of the flight team. The ground team will follow the safety procedures for the aircraft to determine where the issues reside and if this can be fixed on-site using their flight crew's equipment. If the payload bay cannot be opened, the flight crew will take over and ensure the aircraft can safely return to the original take-off site. Then, this site will have the equipment needed to fix the payload bay issue and support another mission to deliver the payload contents.

Risks of Implementing Mitigation: If a UAS is being used in a pandemic or another situation requiring deliveries to the public, there is a chance the person receiving the delivery is not trained to open the payload bay. If the receiver is not trained, the package may not be unloaded, resulting in an unsuccessful mission.

Applicable Disasters:

- Pandemic Case LUAS
- Pandemic Case sUAS

2.7.3.7 *Loss of Power and Data Transfer to Tethered UAS*

Risk: This hazard comes from a lack of continued power and data transfer through the UAS tether. Possible effects include the tethered UAS needing to descend to obtain new batteries, removing the capabilities the UAS provides.

Mitigation: Before the mission starts, the RPIC for the tethered UAS will perform safety checks for the tethering system and verify that power and data can be received by the aircraft and sent back to the ground station. The RPIC and their flight team will monitor the issue to see if there is a drop in power and data transfer. Once it reaches the threshold of its safety limits, the aircraft will descend with sufficient power to ensure a safe landing. All data collected will be removed from the onboard sensors, and the power issue will be evaluated. The aircraft will return to its tethered altitude to provide needed support if possible.

Risks of Implementing Mitigation: This mitigation depends on the aircraft possessing enough battery capacity to land at the designated area. If the aircraft does not have enough battery without the supply from the tether, it may not land safely.

Applicable Disasters:

- Airport terrorism
- Wildfire

2.7.3.8 *Tether Breaks*

Risk: This hazard arises from a broken tether between the ground station and the airborne platform. Possible effects include a free-flying UAS that should be tethered to the ground, which lacks a pre-defined flight route and is in fly-away mode.

Mitigation: The RPIC for the mission will take over manual control of the aircraft and perform a DLI or RTB for the aircraft. The flight crew will use a small UAS that can be both a tethered UAS with data transfer and power provided by the tethered, as well as a mobile UAS that can be manually controlled by the flight RPIC. The flight crew will have a VO that can act if the aircraft does fly away from its tether and will communicate with the RPIC.

Risks of Implementing Mitigation: This mitigation requires that the aircraft communicate with the control station after the incident that caused the tether to break. The aircraft could become a flyaway when it detaches from the tether. There is also the risk that the UAS may not have sufficient battery onboard to land safely.

Applicable Disasters:

- Airport terrorism
- Wildfire

2.7.3.9 *Loss of Telemetry*

Risk: This risk arises when operating a UAS and the GCS or radio loses communication with the aircraft during a mission. This can cause a flyaway, resulting in a crash or crash-landing, leading to injury or damage to property. Challenges posed by natural disasters can increase the likelihood of this hazard occurring.

Mitigation: When planning a mission using any mission planning software, the RPIC must create a safe return path for the aircraft to navigate with a loss of telemetry. This safe return path must ensure that no objects will interfere with the UAS if flying at a safe altitude. During the preflight check, the RPIC must confirm the proper function of the aircraft's telemetry. If the GCS loses signal with the UAS, but the pilot's radio is communicating, the RPIC must be prepared to take manual control of the aircraft.

Risks of Implementing Mitigation: If telemetry is lost while the GPS onboard is not working correctly, the aircraft cannot navigate the safe return path. This could lead to unsafe landings or crashes with other aircraft.

Applicable Disasters:

- Airport terrorism

- Earthquake and Tsunami
- Hurricane, Tornado, and Flooding
- Oil Spill
- Pandemic - LUAS
- Pandemic - sUAS
- Train Derailment
- Volcano
- Wildfire

2.7.3.10 *Unable to Stay Airborne or Takes Too Long to Launch*

Risk: This hazard comes from the time taken to get the UAS airborne to collect data, thus limiting observation time. This can be caused by a need to refuel and restrict high-altitude observations. Possible effects are the unavailability of high-altitude observations and communications hub(s).

Mitigation: The UAS team will react quickly to support the disaster response. They will know the available airports for their flight operations and have the proper flight checklists. The UAS team with assets closest to the disaster response will be contacted first to ensure fast response. The disaster response team will know the available UAS teams that are approved to support a disaster response. The UAS flight crew will inform the Integrated Communications System lead/air boss of the fuel currently available and how long they can stay airborne.

Risks of Implementing Mitigation: Delayed response times may still occur because of logistical issues, such as airport availability and airspace clearance. Coordination challenges with other UAS teams might lead to overlapping flight paths and possible mid-air crashes.

Applicable Disasters:

- Earthquake and Tsunami
- Hurricane, Tornado, and Flooding
- Train Derailment LUAS

2.7.3.11 *Taken Out of Service*

Risk: A specific UAS can provide supplies to ground teams involved in events such as a terrorist event. When the supplies are being delivered, the mechanism fails, and as a result, the supplies cannot be delivered. This means the supplies do not reach those in need, and the aircraft cannot perform its duties.

Mitigation: The RPIC safely returns the UAS to the landing site to allow the engineering members of the flight crew to examine the impacted mechanism, repair it on-site, and allow the UAS to continue its mission. This will minimize the risk that the supplies cannot reach those in need. If the UAS cannot be fixed, a backup UAS will be used, and if needed, a new UAS with a working mechanism will be acquired from the operations center.

Risks of Implementing Mitigation: If repair is necessary for UAS systems, then delays in supply delivery will likely occur. These repairs would also remove crew members from other essential duties or require additional crew, increasing the risk of potential injuries and personnel traffic. On-site maintenance may not be able to be adequately tested before being put into operation, meaning repair errors would not be discovered until in flight, causing potential fly away or control issues.

Applicable Disaster:

- Airport terrorism

2.7.4 Personnel

The following sub-sections represent factors affecting risks and mitigations associated with UAS Personnel and procedures involving UAS responders, crew, and communication elements of on-site responders. While the risks and associated mitigations listed here are not exhaustive, they represent a reasonable cross-section of factors that responders must consider. These risks and their associated mitigations resulted from input from this research and past work from ASSURE A28.

2.7.4.1 *Common Language*

Risk: A lack of common language for UAS operations could lead to miscommunication, confusion, and data collection and interpretation errors. These factors can pose severe risks to the integrity of the UAS mission. Poor operation conduct could lead to delays, tasks being performed incorrectly, loss of control over the UAS, or even potential harm.

Mitigation: Steps can be taken before a UAS operation is conducted to mitigate the possibility that the team does not share a common language. Meetings to establish common terminology for processes, equipment, and units can be used to allow the team to work together and be on the same page. When different languages are spoken, a translator or translating software will prove helpful.

Risks of Implementing Mitigation: If a translator or software is used to mediate a language barrier, the communication chain would be significantly hindered and lengthened. Loss of information between team members and an inability to quickly coordinate developing risk and evasive actions would be likely. Any technical failure in translation software would cut off verbal communication entirely. Team members are also expected to default to previous nomenclature separate from the established common language, which could add confusion and slow down operations.

Applicable Disasters:

- Airport terrorism
- Earthquake and Tsunami
- Hurricane, Tornado, and Flooding
- Oil Spill

- Pandemic - LUAS
- Pandemic - sUAS
- Train Derailment
- Volcano
- Wildfire

2.7.4.2 *Crew Fatigue*

Risk: All UAS will support the ground teams responding to disaster events. The events' timeframe will depend on the disaster's scale and the operational teams' capacity to mitigate the events. This may mean they extend beyond one day, leading to potential fatigue for the flight crews. This can then lead to tired personnel and potential mistakes being made.

Mitigation: If the flight operations extend beyond the safe operational limits of the flight crews' working hours, backup flight crews will be set up to relieve the current operational teams. Debriefs will occur between each crew through the relevant PICs and in coordination with the operations team. This will minimize fatigue placed on the flight crews and reduce the risk of mistakes.

Risks of Implementing Mitigation: When coordinating the handover of operations between teams, the incoming team will need to be adequately updated on the previous team's progress and address any ongoing or new hazards in the area. Any lapse in knowledge will leave the incoming team at risk of operational error. Because the existing team will be resting, they will be unavailable for consultation regarding any forgotten details. The technical difficulty in coordinating between multiple PICs and teams creates points of failure that do not exist with a single pilot.

Applicable Disasters:

- Airport terrorism
- Earthquake and Tsunami
- Hurricane, Tornado, and Flooding
- Oil Spill
- Pandemic- LUAS
- Pandemic - sUAS
- Train Derailment
- Volcano
- Wildfire

2.7.4.3 *Lack of Contact with Flight Service for NOTAM*

Risk: When operating UAS in an area with a natural disaster, other UAS or manned aircraft will likely be nearby. If a NOTAM is not issued for the UAS flight, other pilots will not be aware of an aircraft in their area. This can lead to crashes or emergency maneuvers.

Mitigation: The RPIC will issue a NOTAM and contact Air Traffic Control (ATC) before the flight. The RPIC will also know manned aircraft planning to fly in the area. Based on other aircraft, the RPIC will define a safe flight path and altitude. The flight crew must also remind the RPIC to place a NOTAM if one still needs to be produced.

Risks of Implementing Mitigation: Defining the flight path in response to aircraft on-site means that the flight plan cannot be created before the operation, delaying flight operations and introducing further technical risk. Communication with ATC could create confusion and traffic conflicts with other team members.

Applicable Disasters:

- Airport terrorism
- Earthquake and Tsunami
- Hurricane, Tornado, and Flooding
- Oil Spill
- Pandemic - LUAS
- Pandemic - sUAS
- Train Derailment
- Volcano
- Wildfire

2.7.4.4 *Unsafe Operations Over People or Property*

Risk: This hazard comes from the flight crew's inability to ensure safe flight operations when people and property are below the flight route. Possible effects are a crash of the UAS with people/property or a need to RTB because the RPIC cannot ensure safe flight operations.

Mitigation: Before the mission starts, the RPIC will define all the backup landing zones in case of an issue with the flight operations. The VO will continue to track the aircraft and airspace and inform the RPIC if they cannot continue this role. If the VO loses sight of an aircraft, the RPIC will invoke a DLI or RTB, depending on the location and proximity to people and property. The flight mission will have all the required permissions to allow flight over people and the environment below the flight path.

Risks of Implementing Mitigation: When designating backup landing zones, additional personnel or measures will need to be taken to ensure the area is always clear in the case of a DLI.

This would increase the number of people on-site and the communication traffic. When utilizing a VO for assistance, miscommunication could strain decision-making and increase the risk of an incident. Acquiring the necessary permission to allow flight over populated areas could delay response and require advanced planning.

Applicable Disasters:

- Hurricane, Tornado, and Flooding
- Oil Spill
- Wildfire

2.7.4.5 *Line of Sight (LOS) Flight(s)*

Risk: Manually flown UAS will provide proximal observations of the event and flying under VLOS operations with a VO. The mission may require flying to the maximum extent of observers' view and, as such, would be close to flying outside VLOS. This would mean the flight crew does not have sight of the UAS or the airspace around it.

Mitigation: The RPIC and VO would be in constant contact to ensure they maintain sight of the UAS and surrounding airspace. The VO would inform the RPIC if the flight route reached the extent of their ability to observe the aircraft and surrounding airspace. The RPIC would inform operations to see if it is necessary to push beyond VLOS operations. If so, then the crew would assess the need for extended VLOS. If Beyond Visual Line-Of-Sight (BVLOS) were needed, the flight crew would determine if the UAS has BVLOS capacity and request via SGI to obtain a BVLOS waiver.

Risks of Implementing Mitigation: A significant risk comes from reliance on communication between RPIC and VO. Any communication breakdown when flying the boundaries of VLOS would lead to a substantial lack of situational awareness and a potential flyaway or loss of sight on UAS. When pushing VLOS, any unforeseen obstruction to vision, such as sudden dust or haze, would decrease VLOS, causing the UAS to be in a BVLOS regime. If a BVLOS flight is deemed necessary, obtaining a waiver through SGI would be time-consuming and delay the mission timeline.

Applicable Disasters:

- Airport terrorism
- Earthquake and Tsunami
- Hurricane, Tornado, and Flooding
- Oil Spill
- Train Derailment sUAS
- Volcano LUAS
- Volcano sUAS

2.7.4.6 *Conflicted Frequencies/Frequency Bands*

Risk: Confliction of frequencies could result in a loss of communication between the UAS and ground control crews and navigation errors, especially if multiple UAS are operating on the same band. These risks could lead to loss of control over a UAS, posing significant risks to people on the ground.

Mitigation: Before launching a UAS, ground crews can coordinate with other teams to ensure no other radio devices will be on the same frequency. A UAS should execute a failsafe by hovering, returning to home, or descending until the band is deconflicted if a UAS is already in the air when another device conflicts with its command and control frequency. When a UAS is in the air, ground crews should make it well known what frequency band the UAS is operating on so that no other devices conflict with that band.

Risks of Implementing Mitigation: The complexity of tracking and communicating between multiple frequency bands for different devices could increase the likelihood of human error or oversight, leading to communication conflicts. Rapid and clear communication is necessary if a UAS experiences an in-flight failure. The added risk of implementing failsafe procedures is an increase in deployment time and a potential delay in operation brought on by grounding the UAS. These could push the flight outside of the operating window.

Applicable Disasters:

- Airport terrorism
- Earthquake and Tsunami
- Hurricane, Tornado, and Flooding
- Oil Spill
- Pandemic - LUAS
- Pandemic - sUAS
- Train Derailment
- Wildfire
- Volcano

2.7.4.7 *Loss of Communication*

Risk: This hazard comes from two flight crews and two GCSs used for the UAS operations and a loss in communication between them. Possible effects include the inability of the GCS to track the UAS and the lack of confirmation of a hand-off of the UAS from one GCS to another.

Mitigation: Before the mission starts, the two PICs will check all communications between the two GCSs and backup communication tools to ensure that at least one GCS is tracking the UAS. They will establish a handoff procedure between the two GCSs and a contingency plan for a loss of communication. If there is a drop-in communication, the original take-off site will stay in control of the UAS tracking as they would have been the lead until the handover. If there is no return to joint communications, then the take-off site RPIC will set the RTB on the aircraft, and this will inform the second RPIC that the communication issue has prevented them from completing the mission.

Risks of Implementing Mitigation: Introducing further procedures for the PICs will introduce more complexity to the operation, which could increase the likelihood of human error, such as skipping critical steps or miscommunication, putting the operation in jeopardy. Increased mandated checks and handoffs would create more traffic over communication, which could interrupt operators and other team members, leading to decreased efficiency.

Applicable Disasters:

- Pandemic Case LUAS
- Pandemic Case sUAS

2.7.4.8 *Loss of Time Synchronization Between Multiple Aircraft*

Risk: This hazard would be caused by incorrect timing of missions [multiple aircraft] to match through centralized communications. Possible effects include the aircraft taking off at the wrong time and data not being suitable for evaluating the disaster event.

Mitigation: Before all the missions start, the flight crews will ensure that aircraft systems and GCSs are synchronized to compare data. Between flights, the crew will re-assess the time synchronization of their systems and communicate with the central team to ensure operations occur at the time specified in the CONOP.

Risks of Implementing Mitigation: In mitigating the risk of time synchronization, the time between flights is increased to check GCS and coordinate with the crew. In certain time-sensitive responses, this could lead to further risk brought on by a building weather event or potentially jeopardize a mission if flight conditions become unflyable.

Applicable Disasters:

- Airport terrorism
- Earthquake and Tsunami
- Hurricane, Tornado, and Flooding
- Oil Spill
- Pandemic - LUAS
- Pandemic - sUAS
- Train Derailment
- Volcano

3 SUMMARY

This report summarizes the findings from ASSURE A62 Task 3 and associated sub-tasks. The research team used a combination of subject matter expertise and literature review to address pertinent research questions related to each sub-task. The research team addressed the following sub-tasks and research questions:

Sub-Task 3.1: What are additional use cases that should be explored for UAS supporting disaster and emergency response, recovery, mitigation, and situational awareness missions, including international use cases?

Sub-Task 3.2: What are the operational characteristics and requirements for multi-UAS operations supporting disaster and emergency response and recovery missions?

Sub-Task 3.3: What are additional use cases for UAS supporting future health pandemic response operations?

Sub-Task 3.4: What category of UAS platforms will work with each additional mission type? What are the characteristics of the optimum UAS(s) for disaster preparedness?

Sub-Task 3.5: What lessons were learned from the previous use case demonstrations?

Sub-Task 3.6: Where would UAS not be optimal for use during disasters and emergencies (i.e., manned aircraft may be more efficient at long-range response operations)?

Sub-Task 3.7: What are the risks and safety mitigations associated with UAS supporting a wide variety of disaster and emergency response use cases? What are the risks associated with the implementation of resulting recommendations by disaster and emergency response organizations?

3.1 Summary – Sub-Task 3.1

The research team identified additional use cases spread across four unique types of disasters – Natural, anthropogenic, disaster and emergency response support, and other response operations. Table 67 shows the number of unique use cases associated with each type of disaster.

Table 67. Summary of Additional Use Cases.

Disaster Type	Number of Use Cases
Natural Disaster	12
Anthropogenic Disaster	23
Disaster Response Support	19
Other Response Operations	3

As shown in Table 67, there are at least 57 additional use cases for UAS in disaster response and recovery to explore. Section 2.1 Provides a detailed description of each use case identified and a brief overview of the applicable UAS, sensors, and operational considerations.

3.2 Summary – Sub-Task 3.2

Sub-Task 3.2 identified requirements for multi-UAS operations supporting disaster response and recovery. This task emphasized the need to operate multiple UAS within a disaster area to support responders. This task did not emphasize the 1:n – i.e., "one to many" operational construct for UAS. Instead, it focused on mitigating risks associated with "crowded airspace" during high-tempo disaster response operations where multiple entities may operate different UAS. Findings from this task focused on the need for robust communication, coordination, and deconfliction systems that allow air traffic types to share common airspace blocks.

Findings from Task 3.2 highlighted the importance of UTM systems, shared data and communication, and COPs to provide situational awareness in disaster scenarios. Mitigating the risks associated with many users sharing a block of airspace for different missions requires all users to communicate, share crucial information – e.g., location, altitude, and flight plan- and deconflict in real time to maintain safety. An air boss may use tools like a COP to coordinate between UAS operators, conventional air assets, and other entities in the airspace to maintain safety and ensure operational goals are achieved.

3.3 Summary – Sub-Task 3.3

Sub-Task 3.3 addressed health and pandemic response cases for UAS. These use cases became increasingly relevant with the worldwide SARS-COV-2 epidemic in 2020. They showed a need for UAS use cases to address public health, logistics, and communication needs.

UAS may be used for area disinfection missions, following a similar pattern to an agricultural sprayer. This use case allows UAS to apply disinfectant to larger, open-air areas. However, there are challenges with wind drift and filling gaps in surfaces and buildings. UAS may also be used for UV sanitization, using UV light to kill bacteria and microbes across large outdoor areas.

Healthcare logistics represents another critical use case for UAS. Healthcare logistics networks can become strained in pandemic scenarios, especially when supplies are in critical demand. UAS can deliver supplies, such as vaccines, blood, and personal protective equipment, between locations quickly and efficiently.

UAS may also serve in the role of social monitoring and logistics during pandemic situations. Remote sensing methods and IR sensors may allow them to detect heart rates, temperatures, and people expressing symptoms within a crowd. These capabilities may enable responders to screen large numbers of people quickly for isolation and quarantine.

Finally, UAS may serve in a communications role when supporting pandemic response. One-way loudspeaker attachments may allow them to broadcast messages to the public, allowing critical and time-sensitive messages to be delivered to large crowds. They may also provide QR codes and other forms of messaging to aid responders in delivering critical information.

3.4 Summary – Sub-Task 3.4

This sub-task explored the pairing of UAS, performance capabilities, and sensors to disaster types to identify UAS that are ideal for each mission type and characteristics of UAS and sensors that may achieve the best outcomes. This task generated a set of tables (Tables 58, 59, 60, and 61) that illustrate combinations of UAS, sensors, and capabilities for responders. This task also explored aspects of cyber vulnerability for UAS, providing a brief overview of common attacks across the phases of flight and outlining fundamental methods for assessing risks (Tables 62, 63, 64, and 65).

3.5 Summary – Sub-Task 3.5

This sub-task captured lessons learned from previous demonstrations of disaster response using UAS. Findings for this task are captured in a "lessons learned" report from past ASSURE research, A52. Critical lessons and operational nuances associated with implementing UAS for disaster response are detailed in the ASSURE A52 Lessons Learned report.

3.6 Summary – Sub-Task 3.6

This sub-task served as a point of contrast to Sub-Task 3.4. While Sub-Task 3.4 identified optimal UAS for given disaster response scenarios, findings from this sub-task identified instances when UAS may not be optimal for responders. Findings indicate that employing UAS is based mainly on ensuring one employs the "right tool for the right job," tailoring UAS characteristics to the mission. This finding agrees with the concepts explored in Sub-Task 3.4. However, findings also indicate that employing UAS for disaster response and recovery may be limited by other factors, such as weather, UAS performance characteristics – e.g., endurance and other operating requirements – and regulatory, societal, and cultural considerations. Responders must factor the UAS they intend to employ, its performance, environmental concerns, and regulatory and societal constructs into their pre-mission deployment calculus.

3.7 Summary – Sub-Task 3.7

Finally, Sub-Task 3.7 explored additional risks and safety mitigations associated with various UAS response operations. Findings indicate a significant number of risks and an equally significant number of mitigations that are unique to multiple disaster scenarios. This task also explored the implications of adopting specific risk mitigations, identifying that additional risks are often incurred when adopting mitigations for other risks. Overall findings indicate a need for responders to deeply understand their UAS, crew, crew training, and their established CONOPS.

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Appendix C. Task 4 Technical Research Report

ASSURE A62 – Disaster Preparedness and Emergency Response Phase III

Task 4 – Analysis of Legislation, Policies, Procedures, and Standards

August 27, 2024

v 1.0

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AOBD	Air Operations Branch Director
ASSURE	Alliance for System Safety of UAS through Research Excellence
ASTM	ASTM International
ATGS	Air Tactical Group Supervisor
BVLOS	Beyond Visual Line Of Sight
COA	Certificate of Authorization
COP	Common Operating Picture
DHS	Department of Homeland Security
DOD	Department of Defense
DOI	Department of Interior
DOS	Department of State
DOT	Department of Transportation
FAA	Federal Aviation Administration
FAR	Federal Acquisition Regulation
FEMA	Federal Emergency Management Agency
ICS	Incident Command Structure
IR	Infrared
NAS	National Air Space
NASA	National Air and Space Administration
NDAA	National Defense Authorization Act
NFPA	National Fire Protection Agency
NIMS	National Incident Management System
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NWCG	National Wildfire Coordinating Group
OOMV	Operations Over Moving Vehicles
OOP	Operations Over People
OPA	Optionally Piloted Aircraft
RPIC	Remote Pilot in Command
SAR	Search and Rescue
SDO	Standards Development Organization
SGI	Special Governmental Interest
SOP	Standard Operating Procedure
SOSC	System Operations Support Center
sUAS	Small Unmanned Aircraft System
TFR	Temporary Flight Restriction
UAH	University of Alabama Huntsville
UAS	Unmanned Aircraft System
USFS	United States Forestry Service

EXECUTIVE SUMMARY

This task addressed eight research questions within critical subject areas surrounding legislation, policy, procedures, and standards for implementing UAS for disaster response and recovery. This task and associated sub-tasks identified enablers and roadblocks for UAS integration into disaster response roles. Findings indicate that the National Defense Authorization Act (NDAA), particularly the American Security Drone Act of 2023, dramatically limits the procurement and operations of various UAS. This significantly limits responders' capacity to acquire UAS and integrate them into their routine operations. This research also highlighted the importance of UAS training, specifically training that emphasizes unique skills and procedures applicable to disaster response. A dedicated UAS rating, or equivalent for responders, would be beneficial to train in specific skills and mitigate risk. Similarly, standardizing UAS airworthiness criteria and processes between government entities would provide an added layer of safety. The need for standardization in UAS typing, training, and airworthiness points to a trend worthy of further study. This is especially true when preventing airspace incursions, which will likely rely on a combination of preventative measures to deter hobbyists combined with counter-UAS systems to deal with nefarious actors. Finally, this research identified UAS use trends across numerous organizations and identified challenges with the Special Government Interest (SGI) process.

1 TASK 4 SUB-TASKS

ASSURE project A62, Task 4, was divided into eight (8) sub-tasks. Each sub-task addresses one of eight (8) research questions relating to legislation, policies, procedures, and standards regarding UAS for disaster response and recovery. The following outlines the ASSURE A62 Task 4 sub-tasks and their research questions.

Sub-Task 4.1: What are the impacts of new legislation (such as the National Defense Authorization Act (NDAA)) on local, state, and federal agencies using UAS for disaster and emergency response and recovery missions? What should compliance with this new legislation look like?

Sub-Task 4.2: What are the benefits and impacts of a public safety pilot rating beyond the Part 107 remote pilot rating?

Sub-Task 4.3: What should the additional airworthiness qualifications and crew training procedures look like for disaster and emergency response and recovery UAS operations? Are there any other policies and procedures that need to be developed in order to expand UAS supporting disaster and emergency response and recovery missions?

Sub-Task 4.4: How can UAS incursions during response and recovery missions be mitigated?

Sub-Task 4.5: How can disaster and emergency action plans for UAS supporting response and recovery be standardized across local, state, and federal agencies?

Sub-Task 4.6: Investigate the UAS fleet mix of local, state, and federal disaster and emergency response organizations and determine the priority of policies and procedures for the future growth of fleets from organizations.

Sub-Task 4.7: Coordinate with the Federal Emergency Management Agency (FEMA) and the National Wildfire Coordinating Group (NWCG) to determine what UAS typing standards would look like.

Sub-Task 4.8: How can concerns be mitigated regarding the issuance of Special Government Interests (SGIs)? Look at FEMA's processes regarding an Air Ops liaison.

2 RESEARCH FINDINGS FOR SUB-TASKS

The following sections address the research team's answers to the research questions. They highlight findings from research, subject matter expertise, and additional literature reviews. The findings listed in the following section represent the primary deliverable to satisfy the requirements for ASSURE A64 Task 4 – *Analysis of Legislation, Policies, Procedures, and Standards.* The following sub-sections discuss the findings for each sub-task.

2.1 Sub-Task 4.1 – Impacts of Legislation

The University of Alabama Huntsville (UAH) reviewed in detail the 2024 NDAA, which became law on 22 December 2023. The NDAA covers policies and authorizations for the Department of Defense (DOD) military budget (Armed Services, 2024). The NDAA has provisions for federal programs beyond the DOD that relate to national security. For example, the Department of Energy, the Maritime Administration, the Department of State (DOS), the National Oceanic and Atmospheric Administration (NOAA), and the Department of Homeland Security (DHS). Specifically, the NDAA authorizes $858 billion for national defense budgets related to:

1. Procurement,
2. Research, Development, Testing, and Evaluation,
3. Operations and Maintenance,
4. Military Personnel and Health,
5. Military Construction, and
6. Defense Relation Nuclear Programs.

In particular, the legislation review for Task 4-1 sought to identify the impact on multiagency coordination with local, state, and federal agencies to respond to disasters, including operational protocols, resource allocations, and potential technology gaps between market leader UAS and those compliant with NDAA "drone security" requirements. Additional review topics include compliance costs, procurement requirements, and training programs related to disaster response efforts.

Many of the review topics relevant to this task may be found under *Title XVIII – Other Defense Matters, Subtitle B – Drone Security, also known as the "American Security Drone Act of 2023"* in the NDAA legislation. However, the UAH team identified several other areas that may have tangential impacts on local, state, and federal agencies responsible for disaster and emergency response, outlined in this deliverable.

2.1.1.1 *American Drone Security Act of 2023*

The American Drone Security Act is a component of the NDAA. It sets legal requirements for government entities' procurement and UAS operations. The following sections outline its impact on government entities, including its effects on public safety entities that may use UAS to support disaster response and recovery operations.

2.1.1.1.1 Procurement and Operations

Regarding federal agency compliance under the NDAA, there are several requirements on the procurement, operation within the National Airspace System (NAS), use of federal funds for both procurement and operations in the NAS, and UAS inventory management for what is referred to as "covered UAS" originating from "covered foreign entities." Covered foreign entities is a term defined as any entity that is subject to extrajudicial direction from a foreign government that has been identified as posing a risk to national security by a joint review by the Attorney General, DOD, DHS, Director of National Intelligence, and the Department of Justice. Covered unmanned aircraft are all components of a UAS, both hardware and software, originating from a covered foreign entity. An example of a covered foreign entity and UAS provided in the legislation is any manufacturer in the People's Republic of China. Sections of the legislation that pertain to these matters within the "American Drone Act of 2023" are outlined in Table 1 with a brief summary.

Table 1. Summary of American Drone Act of 2023; Sec. 1823 – 1827.

Section #	Related Federal Agency	Summary
Sec. 1823	DOT, DHS, NOAA, DOD, DOS	This section outlines the **prohibition of procuring UAS from covered foreign entities** to include all components used in the command and control and data transmission of the UAS, such as the transmitter, telecommunication links, flight controller, and associated software. Airframe, power supply, and other electronic components are included in the definition of UAS and are also prohibited. Exemptions to this prohibition are made available to federal agencies by way of a case-by-case waiver process. This process established by the head of the respective agency but must be approved by the Director of the Office of Management and Budget and the consulted with Federal Acquisition Security Council. Notification to the Committee on Homeland Security and Governmental Affairs in the Senate and the congressional Committee on Oversight and Accountability must also be notified of the waiver. Eligible exemption activities include the procurement of covered UAS for research, evaluation, testing, training, and analysis for Counter-UAS development, counter-intelligence and security investigations, and modification to UAS rendering them NDAA compliant, i.e., no longer posing a cybersecurity risk. Other eligible activities also extend to science and public safety data collection missions, for example by NOAA and the DOT.
Sec. 1824	DOT, DHS, NOAA, DOD, DOS	This section effectively mimics the previous section on prohibition of covered and exemption eligibility but relates specifically to the **operation of covered UAS in the NAS.** However, this prohibition extends to contracted services working for federal agencies using covered UAS. A joint effort between the Attorney General and the Department of Transportation (DOT) is required to provide regulatory guidance on how to

		implement these operational rules and exemption process.
Sec. 1825	DOT, DHS, NOAA, DOD, DOS	This section defines the **prohibition of using federal funds to sponsor the procurement and operations using covered UAS**. This prohibition extends to the use of federal funds by way of contracts, grants, and cooperative agreements. The exemption process reflects that of the other sections listed above.
Sec. 1826	DOT, DHS, NOAA, DOD, DOS	This section defines the prohibition of government issued purchase cards (P-Cards) to purchase covered UAS and is effective immediately.
Sec. 1827	DOT, DHS, NOAA, DOD, DOS	Federal agencies must account for all covered UAS in existing aviation inventories. Management of these inventories must be conducted at a classified level for tracking purposes. Exemptions to relevant federal agencies with inventories containing covered UAS is only eligible for UAS that are designated as low-cost, one-time use, or expendable.

The sections listed in Table 1 explicitly prohibit certain UAS assets that cannot be purchased with federal funds. This prohibition extends to operations of covered UAS in the NAS as well. Exemptions for certain activities relevant to this review, such as science and public safety data collection missions conducted by federal agencies responsible for disaster and emergency response, are allowed but may present a challenge in the short term for agencies relying on systems manufactured or assembled in covered foreign entities.

Table 2. Summary of American Drone Act of 2023; Sec. 1829.

Section #	Related Federal Agency	Summary
Sec. 1829	DOT, DHS, NOAA, DOD, DOS, NIST	This section **mandates the development of a government-wide policy for procurement of UAS** in a manner that does not pose a risk to federal information security. This policy is directed towards non-DOD operations, non-Intelligence Community operations, and operations supporting grants and cooperative agreements with the federal government. This policy is developed in partnership with the National Institute for Standards and Technology (NIST) to provide guidance on controlled access to UAS hardware and software aiming to safeguard sensitive federal information. A requirement to update policy reflected this standard also extends to any

		federal entity that is not directly subject to the Federal Acquisition Regulation (FAR).

The sections described in Table 2 provide insight into government-wide and non-defense, non-intelligence community policies related to procurement and cost of UAS. The legislation refers to this as a government-wide policy for procuring UAS that meet NDAA data security requirements. These requirements extend to federal programs that are subject to FAR but also now to programs that are not directly subject to FAR. Sponsored programs through "Other Transaction" authorities have been provided to eleven federal agencies to fund research and development or prototype programs through funding vehicles outside of contracts, grants, or cooperative agreements. This government-wide policy may present challenges similar to those faced by federal agencies or partner institutions when performing disaster and emergency response due to pending restrictions on allowable UAS procurement policies.

Table 3. Summary of American Drone Act of 2023; Sec. 1830.

Section #	Related Federal Agency	Summary
Sec. 1830	Local, State, and Territorial Agencies	This section explains that the NDAA **does not prohibit local, state, and territorial law enforcement and emergency services agencies from procuring or operating covered UAS** purchased with non-Federal dollars. The federal government may continue contracts, grants, and cooperative agreements with local, state, and territorial agencies who operate covered UAS as long as long as the waivers described in previous sections of the American Drone Security Act of 2023 have been approved.

Section 1830 (Table 3) provides the most direct impact of the NDAA on local, state, and territorial agencies responsible for disaster and emergency response. Although there are no direct prohibitions to these agencies on procurement and costs for non-federal funding, there is a requirement to comply with the waiver process for federal agency collaboration. The potential challenge may result in the timeliness of the regulatory guidance on the waiver process or the commitments required in waivers, which may hinder multiagency coordination efforts in disaster response. The Incident Command Structure (ICS) and other disaster response frameworks from the federal government have explicit requirements for data sharing and information security, including that of aerial imagery and geospatial products, which may reflect that of the operational waivers for covered UAS operated by supporting agencies in disaster response. Having these waivers and approvals before disaster strikes would facilitate a rapid response. However, this is not always practical as disasters are often unpredictable and do not always fall within the confines of pre-existing waivers or other operational approvals.

Table 4. Summary of American Drone Act of 2023; Sec. 1831.

Section #	Related Federal Agency	Summary
Sec. 1831	DOT, DHS, NOAA, DOD, DOS, Local, State, and Territorial Agencies	This section mandates a requirement for the Under Secretary of Defense for Acquisition and Sustainment to **carry out a study investigating the challenges of the supply chain and future demand for UAS and supporting components**. The resulting report must include a trade study of domestic and global trends in the UAS market, availability and sustainability of commercial UAS that are not from covered foreign entities, and a plan to address the challenges in availability of UAS not from covered foreign entities through the Defense Production Act.

A trade study identifying the gaps and challenges for supplying commercial UAS hardware and software from manufacturers other than covered UAS (Table 4) provides an opportunity to increase competition in the UAS market. With the prohibitions on procurement and operations of a significant portion of the global UAS market, there is a strong demand amongst all levels of government to have alternative sources of secure, functional UAS. Public safety agencies are often more constricted by funding availability to purchase UAS used in DOD-type operations or cannot modify covered UAS to comply with NDAA information security requirements. The availability of NDAA-compliant hardware and software will offer more options to agencies responsible for disaster and emergency response to facilitate multiagency coordination efforts.

Table 5. Summary of American Drone Act of 2023; Sec. 1832.

Section #	Related Federal Agency	Summary
Sec. 1832	DOT, DHS, NOAA, DOD, DOS, Local, State, and Territorial Agencies	This section provides three key exceptions to the American Drone Security Act of 2023. Specifically, federal agencies procuring and operating UAS supporting wildfire management and Search And Rescue (SAR) operations, federal agencies performing intelligence activities under the Title V of the National Security Act of 1947, and Tribal Law Enforcement or Emergency Services agencies.

Three explicit exceptions to the prohibition of procurement and operations have been outlined in the NDAA (Table 5). The full range of wildfire management and SAR operations conducted by federal government agencies operating under DHS are exempt from carrying out lifesaving missions. Certain intelligence activities related to counterterrorism, counterproliferation, counternarcotics, counterintelligence, and vulnerability assessments of major systems, as outlined in Title V of the National Security Act of 1947, are also exempt. Lastly, law enforcement and emergency services on Tribal Lands are exempt. These exceptions represent very specific disaster and emergency response mission sets conducted by DHS and supporting local, state, and tribal agencies.

2.1.1.1.2 Other Areas of Potential Impact

The NDAA review also identified two other tangential sections that may impact public safety. The first is Title III – Operation and Maintenance, Subtitle B - Energy and Environment, Section 311 – Improvement and Codification of Sentinel Landscapes Partnership Program Authority. This section discusses a US Department of Agriculture program, the Sentinel Landscapes Initiative, to create partnerships amongst local, state, federal, and nongovernmental organizations to address sustainability practices around military installations (USDA, 2024). While the aforementioned American Drone Security Act of 2023 outlines specific restrictions on UAS procurement and operations in the NAS, the DOD may partner with agencies to coordinate land management activities, including UAS. While this section does not inherently discuss disaster and emergency response activities, it indicates partnering with agencies that may continue identifying avenues to partner with agencies and organizations using covered UAS. The waiver processes would most likely be a requirement, as any other requirement for operating UAS near military installations.

The second tangential policy refers to Title VIII – Acquisition Policy, Acquisition Management, Related Matters, Subtitle C – Domestic Sourcing Requirements, Section 831 – Emergency Acquisition Authority for Purposes of Replenishing United States Stockpiles. This section refers to the emergency use of raw materials in the National Defense Stockpiles, which consists of many critical materials, including minerals used in battery production. This stock is allocated explicitly for defense articles in homeland attacks, but the "Emergency Access to Strategic and Critical Materials" congressional report indicates natural disasters are also eligible (Keys, 2023). In extraordinary circumstances, it can be speculated that rapid manufacturing of power supplies, like batteries, necessary to operate UAS in the NAS may considered under the previous section carrying out a trade study of the availability of commercial UAS components.

2.2 Sub-Task 4.2 – Impacts of a Public Safety UAS Pilot Rating

Creating specialized public safety UAS training and remote pilot certification procedures that extend beyond the existing Part 107 remote pilot certification could provide significant benefits for public safety operators. While this training may not necessarily result in a formal rating referenced within FAA regulations, it could be developed within the public safety sector and supported by consensus standards and established best practices. This would provide the equivalent of an industry-supported remote pilot certification built around public safety applications. An advantage of developing a public safety UAS certification with knowledge and practical requirements is that it could define a common training curriculum with broad applicability for public safety entities. Setting baseline requirements for public safety UAS remote pilots could also allow greater latitude to operate by mitigating risk through demonstrated ability – i.e., core competencies. However, these benefits would also have drawbacks, such as costs and resource burdens. The following sections discuss the pros and cons of developing and implementing a public safety UAS remote pilot certification.

As previously mentioned, one of the foremost advantages of such a certification would be the enhanced training and competency it would offer. Unlike Part 107 certification, which covers basic UAS operations and requires no practical flight training, a public safety-specific certification could include emergency response and disaster management training, emphasizing critical knowledge and practical skills. This specialized training would better equip pilots to handle high-stress situations, make quick, informed decisions, and operate safely in dynamic environments. Established industry consensus standards, such as ASTM F3266 *Training for Remote Pilot in Command of Unmanned Aircraft Systems (UAS) Endorsement*[1] and ASTM F3379 *Standard Guide for Training for Public Safety Remote Pilot of Unmanned Aircraft Systems (UAS) Endorsement*[2] may define this training. Leveraging other existing industry consensus standards from ASTM International and other Standard Development Organizations (SDOs), such as the National Institute for Standards and Technology (NIST) and the National Fire Protection Association (NFPA), may also be beneficial. Leveraging industry consensus standards to build training programs enables a standardized approach to developing and delivering training nationwide that is scalable, flexible, and broadly applicable. This approach provides a solid foundation for developing and delivering public safety UAS training that is relevant and rooted in accepted best practices.

Implementing a system that promotes standardized training and remote pilot competency could substantially improve safety and operational efficiency. Training focused on advanced situational awareness, communication protocols, and coordination with other emergency services could lead to safer UAS operations in complex and potentially hazardous settings. This enhanced competency ensures that public safety UAS operations can be conducted more efficiently and with a higher degree of safety for the public, responders, and remote pilots. Standardizing this training would also make it broadly applicable and scalable to the needs of public safety officials.

Another significant benefit of a public safety remote pilot certification is the potential for advantages associated with obtaining operational waivers, enabling greater ease of obtaining operational approvals. Public safety operations often require flying under conditions or in areas restricted under Part 107, such as Beyond Visual Line Of Sight (BVLOS), operations over people (OOP), operations over moving vehicles (OOMV), or multi-UAS control. A specialized remote pilot certification could ease or even eliminate the process of obtaining certain waivers and exemptions from the FAA by demonstrating remote pilot competency as risk mitigation. This could allow for more flexible and effective emergency response operations. Regulatory flexibility is crucial for public safety agencies to perform timely and effective operations in various emergency scenarios.

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[1] ASTM International. (2023). *ASTM F3266-23 Standard Guide for Training for Remote Pilot of Unmanned Aircraft Systems (UAS) Endorsement*. ASTM International. West Conshohocken, PA. https://www.astm.org/Standards/F3266.htm

[2] ASTM International. (2020). *ASTM F3379-20 Standard Guide for Training for Public Safety Remote Pilot of Unmanned Aircraft Systems (UAS) Endorsement*. ASTM International. West Conshohocken, PA. https://www.astm.org/Standards/F3379.htm

The broader operational capabilities of certifying public safety remote pilots could also be substantial. Remote pilots with this advanced certification could legally perform a wider range of critical missions by leveraging competency for gains in operational safety. Missions include but are not limited to hazardous materials and SAR response BVLOS, surveillance during large public events with OOP, and traffic accident investigation with OOMV. Additionally, operating multiple UAS simultaneously would enhance the capability and reach of public safety operations, providing more comprehensive coverage and quicker response times. These expanded capabilities are essential for addressing public safety agencies' diverse and complex challenges.

Furthermore, those with a public safety remote pilot rating could contribute valuable data and insights to ongoing research and further development of industry standards through participation in standards development groups. Standards such as ASTM F3379 *Standard Guide for Training for Public Safety Remote Pilot of Unmanned Aircraft Systems (UAS) Endorsement* and related standards from other SDOs such as NIST and NFPA may shape public safety remote pilot training and certification. The real-world data and operational feedback remote pilots provide could help shape future standards, policies, and regulations. This would improve the overall safety and efficacy of public safety UAS operations. These contributions are vital for the continuous improvement and safe integration of UAS into the NAS for public safety and disaster response.

However, creating a specialized public safety UAS certification also presents significant challenges, mainly related to time commitment and financial costs for public safety entities. This advanced certification would require extensive training, which could take several weeks or months to complete. This includes initial certification and ongoing education to stay current with evolving UAS technology and regulations. The time commitment could be substantial and often challenging for public safety personnel who must balance training with their regular duties. Additionally, gaining practical flight experience is a crucial part of the training, which usually involves realistic simulations of emergency scenarios and practical flight evaluations. This could be logistically challenging and time-consuming.

Financially, the costs associated with obtaining a specialized public safety remote pilot certification could be considerable. Enrollment in advanced training programs, access to high-quality UAS equipment and software, and potential travel expenses for specialized training facilities may contribute to the financial burden. These costs may be particularly challenging for smaller agencies with limited budgets. Moreover, the ongoing costs for recertification and refresher courses add to the long-term financial impact. Public safety agencies must also consider the opportunity costs, as time spent on training can affect the availability of personnel for regular duties, potentially impacting overall agency efficiency and resource allocation. Public safety entities must weigh the costs of pursuing advanced training against the benefits it may provide when budgeting for UAS programs. While specialized remote pilot training for public safety entities may offer increased costs in terms of travel, annual budgeting, and opportunity costs due to unavailable resources, it may also provide enhanced operational latitude that must be factored into decision-making. Public safety entities that train remote pilots and seek a [notional] public safety remote pilot certification should perform a cost-benefit analysis to scale the cost of training and UAS deployment capabilities to their operational needs.

One avenue to potentially ease the personnel and financial burdens of public safety UAS training is to capture training in a graduated structure that distributes costs and time commitments. Public safety UAS training, such as that provided by the FAA's Center of Excellence, the Alliance for System Safety of UAS through Research Excellence (ASSURE), provides a training program that can be structured to accommodate such cost and personnel concerns. This training program, ASSUREd Safe, offers multiple levels of UAS training for public safety, emergency management, and government personnel.[3] Such standardized training has the potential to mesh with established FEMA certification courses, which adopt a similar structure and may incorporate references to [upcoming] 14 CFR Part 108 regulations. The result would be training programs that are scalable to a wide variety of public safety entities with different constraints in terms of time, personnel, and department resources. The additional benefit is that training incorporating ASSUREd Safe and applicable FEMA certifications could stack credentials, allowing public safety entities to tailor training to their specific needs. In summary, while a specialized public safety UAS rating offers substantial benefits in enhanced training, improved safety, broader operational capabilities, and regulatory advantages, it also entails significant time and financial investments. Balancing these costs with the operational benefits will be crucial for effectively implementing and utilizing this advanced certification in public safety contexts. Agencies must carefully consider these factors to ensure that the investment aligns with their operational goals and budget constraints. Agencies with more constrained resources may also wish to utilize interagency agreements and resource sharing if available. This may reduce training and operational costs while capitalizing on existing resources shared between smaller or rural communities.

2.3 Sub-Task 4.3 – Airworthiness Qualifications, Crew Training, and Procedures

The National Incident Management System (NIMS) released the resource typing for UAS operational qualifications in 2018 and was most recently updated in 2023 (Department of Homeland Security, 2024). The NIMS framework is the standard for all emergency management personnel for any scale of response, from local to multiagency coordination efforts. Resource typing defines training requirements, resource category, overall function, and tasking specifications for any asset used in a disaster and emergency response. NIMS has identified two UAS Position Qualifications and one Resource Typing:

1. Remote Pilot-in-Command (RPIC) – *Position Qualification*
2. Technical Specialist – Small Unmanned Aircraft System – *Position Qualification*
3. Small Unmanned Aircraft System (sUAS) Team – *Resource Typing*

Appendix A contains the NIMS documentation for these three resources based on their expected disaster and emergency response mission sets and the coordination requirements for mobilizing and demobilizing these units.

Additional qualifications and training for UAS operations for disaster and emergency response agencies may lie in specialist areas or specific mission sets within the ICS. DHS oversees the development of UAS ICS courses to help define specialist training and qualifications where emergency management personnel may become knowledgeable in UAS operations. One area of particular interest is the development of an "Air Boss" qualification for UAS operations

[3] https://assuredsafe.org/

management. This role would serve as the liaison for UAS operations within the Air Operations Branch or tactical groups of the ICS. Other qualifications may include specialization in certain mission sets, such as law enforcement, SAR, and Disaster Situational Awareness and Reconnaissance. The use of specialized sensors or UAS payloads and the effective processing of data products also present areas of new qualifications, such as the use of thermal infrared, multispectral sensors, hyperspectral sensors, and geospatial intelligence. Identifying unique applications for UAS capabilities in all phases of emergency management (Mitigation, Preparedness, Response, and Recovery) may present other areas of specialization for UAS teams and lead to other operational qualifications for UAS teams to achieve.

2.3.1 Airworthiness Qualifications

In addition to exploring NIMS resource typing and RPIC position qualifications, the research team identified foundational airworthiness qualifications for remote pilots and UAS for disaster response and recovery operations. What follows are recommendations for baseline airworthiness certification standards and crew training procedures. While the following list is not necessarily exhaustive, it creates a baseline for UAS airworthiness and crew training considerations for disaster response missions. The concepts in this section may mesh with NIMS resource typing and position qualification(s) for remote pilots.

2.3.1.1 *Certification Standards*

14 CFR Part 3 defines Airworthy as: "The aircraft conforms to its type design and is in a condition for safe operation." There are currently two classifications of airworthiness certificates:

1. Standard Airworthiness Certificate, and
2. Special Airworthiness Certificate.

Currently, the only certificate for airworthiness a UAS operator can obtain is a Special Airworthiness Certificate under Experimental Category to UAS, Optionally Piloted Aircraft (OPA), and aircraft intended to be flown as either a UAS or an OPA under the designation "OPA/UAS." This does not allow access to the NAS and restricts the types of operations and locations based on the UAS system. This is not the best way to approve a UAS for emergency operations.

Another way is to obtain a Certificate Of Authorization (COA)/Waiver by describing the processes used to determine whether a UAS is safe to operate in the NAS and how it will operate. The FAA approves those operations with specific restrictions, including locations and altitudes. The United States Forestry Service (USFS) has several waivers and authorizations, including BVLOS. The United States Department of Interior (DOI) has several authorizations and waivers.

Another option is to pursue operations under Title 14 CFR Part 107 for aircraft less than 55 lbs. – sUAS. Title 14 CFR Part 107 states:

> (a) No person may operate a civil small unmanned aircraft system unless it is in a condition for safe operation. Before each flight, the remote pilot in command must check the small unmanned aircraft system to determine whether it is in a condition for safe operation.

> (b) No person may continue flight of the small unmanned aircraft when he or she knows or has reason to know that the small unmanned aircraft system is no longer in a condition for safe operation (Condition for Safe Operation, 2016).

The responsibility for determining airworthiness is put squarely on the RPIC, which is reflected in the regulations.

Currently, each government organization has its way of determining airworthiness. USFS uses ASTM F3298-19, DOI references the National Aeronautics and Space Administration (NASA) or internal processes if NASA hasn't reviewed the system, and the Federal Emergency Management Agency (FEMA) references the Interagency Board, which uses the FAA Part 107 requirements.

A proposed approach is to establish one airworthiness standard throughout emergency response organizations. Establishing an approved list of UAS for emergency operations would also be beneficial. This list would consider smaller organizations' costs and mission requirements requiring multiple platforms and capabilities. It would also require manufacturers to establish more detailed maintenance schedules for component repair or replacement.

2.3.1.2 *Inspection Protocols*

Manufacturers should be required to prepare more detailed recommended pre-flight assessments to determine the status of components. They should also establish robust maintenance schedules/inspection processes to catch failures before they happen. These processes would contribute to the initial and continuing airworthiness of UAS.

2.3.1.3 *Durability Testing*

Evaluating a UAS for durability directly affects its cost, affecting what organizations can afford a UAS. This needs to be a tiered approach, keeping small UAS affordable with an acceptable lower lifetime on components. For systems with greater operational capabilities and cost (greater than 55 lbs., greater speed potential over 100 mph, heavier payloads), durability testing should move closer to that of manned aircraft. Materials traceability is completely missing in UAS and may be necessary for critical components.

2.3.2 Crew Training Procedures

The following recommendations identify best practices for remote pilot training. They are rooted in foundational concepts built upon establishing a training curriculum, scenario-based training, and conducting exercises to keep skills sharp. The research team also recommends recurrent training to ensure skills remain current.

2.3.2.1 *Training Curriculum*

The research team recommends establishing a national standard for UAS training using the USFS or similar training as a guide. This is beyond the minimum for obtaining a Part 107 remote pilot certificate with sUAS privileges and visual observer responsibilities. Recommendations also reflect the need to determine the minimum UAS training required and potential system carding to be able to participate in significant disaster relief operations. Specific training should be required to integrate into disaster relief operations, unlike that of Emergency Medical Services flight crews.

2.3.2.2 *Emergency Scenarios*

A proposed approach to ensure adequate RPIC training for emergency scenarios is establishing normal flight operations scenarios to maintain currency between actual deployments. This training would include emergency procedures and training requirements for system malfunctions. Implementing joint training exercises that cover disaster response scenarios and wildland fire management techniques would be especially beneficial.

2.3.2.3 *Simulation Exercises*

Simulation exercises are excellent tools for building RPIC proficiency. Establishing simulation exercises for the RPICs to practice potential disaster/recovery operations would help to maintain proficiency and develop core competencies. These exercises could be generic and may be representative of multiple UAS platforms. Scenarios may simulate system emergencies such as link failure, allowing the RPIC to practice emergency procedure training without risk to the UAS or the public.

2.3.2.4 *Certification/Recertification/Annual Flight Check/Currency*

Recertification, annual flight evaluations, and building systems that ensure continued competency for RPICs require establishing the above certification requirements. This includes determining recertification requirements using a certified Disaster UAS instructor. Robust RPIC certification and recertification would require an annual or, at a minimum, semi-annual training/check to confirm currency. This would also establish a minimum Disaster UAS remote pilot flight time.

2.3.2.5 *Compliance with Regulations*

Recommendations include developing and using a carding system. This system would require specific training regarding UAS emergency response integration, airspace, and communication requirements. A carding system implies that entities would institute an "If you are not properly carded (trained), you cannot participate" policy.

2.3.3 Additional Policies and Procedure Ideas

The following sections represent additional ideas from the research team regarding policies and procedures that may benefit public safety entities that use UAS for disaster response. These ideas cover various topics ranging from operational guidelines to procedures for data management and incident reporting. They provide recommended best practices for UAS operation for public safety operators.

2.3.3.1 *Operational Guidelines*

Establishing functional operational guidelines may require an initial look at existing organizations' methodologies, such as the USFS and DOI, for integrating sUAS into flight operations. Operations will use Temporary Flight Restrictions (TFRs) to reduce the likelihood of non-participating aircraft entering the airspace.

2.3.3.2 *Safety Protocols*

Foundational safety protocols should rely on establishing a well-defined airspace control procedure. This will require voice communications before the start of UAS operations, and all RPICs must have a ground-to-air communication capability. In the event of lost voice communications, a UAS must land, and the RPIC must communicate with the incident commander.

2.3.3.3 *Data Management*

More research must be done to simplify data processing and get the information to the incident commander in real time. Until there are more simplified ways to view data acquired by UAS, it is imperative to have data managers trained in systems, data processing software, and ways to communicate that information to incident commanders.

2.3.3.4 *Interagency Coordination*

This is the most challenging yet essential part of disaster management/relief. The drive for standard, consistent interagency coordination must come from a federal level to ensure all potential participants can/will comply with requirements. Training that reinforces the need for interagency coordination may include establishing operating procedures and equipment requirements followed by low or no-cost participant training, similar to FEMA's current UAS training program.

2.3.3.5 *Incident Reporting*

Recommendations include ensuring all operators and organizations participate in Incident Reporting. This is critical to identifying operational changes or UAS requirements to ensure safe operations. Reporting must be without criminal repercussions to ensure total participation.

2.4 Sub-Task 4.4 – Mitigating UAS Incursions During Response Missions

Mitigating UAS incursions during response and recovery missions requires measures to address two types of airspace incursions: Those from ignorant or careless UAS operators and those of nefarious actors, with the latter case expected to be infrequent. To that end, mitigating UAS incursions will likely consist of measures that address both cases uniquely, emphasizing the need to correct errant hobbyists and stop nefarious UAS that stray into an operation area. Addressing these scenarios will likely incorporate built-in measures to detect and track UAS, technological solutions to raise awareness of public safety and disaster response operations, and identification and tracking of UAS that may pose a safety risk to responders. Strategically, training and certification programs for public safety should include components on managing and mitigating UAS incursions. This training should include an overview of related regulations and the importance of educating the public about the legal and safety implications of flying drones near emergency sites, deterring hobbyists and non-essential operators. Recent regulatory changes that mandate remote ID for UAS, collaboration with industry to derive technological solutions for situational awareness, and the implementation of counter-UAS systems may aid in mitigating the risk of airspace incursions.

Recent regulatory changes, such as the passage and enforcement of Title 14 CFR Part 89 – *Remote Identification of Unmanned Aircraft*[4], provide a layer of detection capability for first responders via a UAS's remote ID module. This same capability extends to hobbyists as well, allowing for mutual visibility. Remote ID offers a readily available tactical means to detect potential airspace incursions during response and recovery missions using readily available equipment, such as a smartphone or tablet. The mandatory requirement to equip UAS with remote ID allows responders to monitor the airspace and identify any UAS that may intrude upon their operation areas. Remote ID will enable responders to identify UAS in the vicinity of their operations organically and take further measures to locate and inform nearby UAS operators of any additional risks their operations present.

Furthermore, responders may seek technological mitigations to airspace incursions through collaborations with the private sector and increased public transparency. Technological solutions can enhance safety by providing built-in drone features that notify the non-participating RPICs and hobbyists of restricted zones – i.e., TFRs. Technological mitigations may also use situational awareness tools, such as systems that generate a Common Operating Picture (COP), to create live activity feeds in given airspace blocks that increase situational awareness and offer public transparency for ongoing response operations within a specified area or a TFR. A COP could provide responders and, to an extent, the public with valuable information regarding ongoing response and recovery operations. Technological mitigations, particularly those that provide operational transparency, are crucial for preventing airspace incursions and potential mid-air collisions.

Public safety agencies may also leverage advanced counter-UAS systems to improve their response capabilities for nefarious UAS that wander into their operation areas and pose an immediate safety risk. These counter-UAS systems may not necessarily involve taking over unauthorized drones but instead focus on detecting and identifying the location of the RPIC. Technologies such as RF detection systems can pinpoint the UAS's and its operator's control signals. Once the RPIC's location is identified, public safety officials can directly communicate with the operator about how their flight interferes with the ongoing incident response.

These approaches have several benefits. First, they offer a tiered approach, relying on mandatory remote ID equipage for UAS identification and localization, followed by a counter-UAS solution that may work without a remote ID module. Both methods allow for a non-confrontational resolution by allowing the RPIC to voluntarily cease their operations once they understand the situation, with the latter being effective when there is an imminent threat to operational safety. They also enhance situational awareness for public safety teams and promote greater transparency, ensuring broad awareness of airborne assets and enabling effective coordination. Additionally, direct communication with remote pilots can serve as an educational moment, informing hobbyist drone operators about the regulations and the importance of keeping clear of emergency response activities.

[4] https://www.ecfr.gov/current/title-14/chapter-I/subchapter-F/part-89

Implementing these strategies requires investment in technology and training for public safety personnel to interpret and act on the information these systems provide. Collaboration with manufacturers to ensure compatibility and effectiveness of detection tools is crucial. Integrating remote ID and advanced counter-UAS measures allows public safety agencies to manage airspace during critical operations better, reducing the risk of hazardous airspace incursions and enhancing overall mission safety and efficiency. Similarly, using new tools to promote public awareness of emergency response and recovery operations offers a path to decrease the likelihood of airspace incursions by informing hobbyists of ongoing public safety activities.

2.5 Sub-Task 4.5 – Standardizing Practices for UAS Disaster Response

Standardizing UAS response and recovery procedures across local, state, and federal agencies could be challenging, but it would provide pathways to safer routine operations. Standardization on such a scale requires coordination through and across multiple levels of state, local, and federal agencies. It also involves harmonizing smaller, often disconnected, response teams across various states, counties, and municipalities that may operate differently. While not an insurmountable challenge, standardizing UAS for emergency response and recovery will require a clear set of national guidelines and established best practices to create net benefits for responders.

On the national level, clear policy guidance would go a long way toward standardizing disaster and emergency response plans for UAS responders. Like other aspects of aviation, standardization would enable public safety remote pilots across multiple agencies to capture best practices for common operations nationwide. Standards and best practices may be referenced by policy and used as guidance to support existing regulations, ensuring commonality between departments and agencies nationwide. Clear guidance in the form of standards for emergency response plans and response and recovery operations could harmonize responders at federal, state, and local levels. Harmonization could simplify training, reduce costs, and make public safety operations safer and more efficient.

Examples of existing standards, such as ASTM F3379 from ASTM International, represent opportunities to reference existing standards to harmonize training for public safety remote pilots. Similarly, standard test methods provided by the NIST[5] and NFPA[6] may provide opportunities to build standardized training across multiple agencies. Ultimately, standardized training methods, competencies, and programs will enable broad standardization across the nation if they are supported by carefully crafted policy guidance that promotes the growth and implementation of UAS for disaster response and recovery.

2.6 Sub-Task 4.6 – UAS Fleets and Policies of Local, State, and Federal Organizations

A survey was distributed to over 2,000 public safety agencies across the United States to address this research question. A total of 152 responses were received, providing valuable data for the assessment. The following summary outlines the key findings and recommendations for

[5] https://www.nist.gov/el/intelligent-systems-division-73500/standard-test-methods-response-robots/aerial-systems/aerial

[6] https://www.nfpa.org/codes-and-standards/nfpa-2400-standard-development/2400

prioritizing policies and procedures for the future growth of public safety UAS fleets. Appendix B provides a list of questions from the survey.

The survey reveals a varied composition of UAS fleets among local, state, federal, and other organizations, such as private companies and academic institutions (Figure 1).

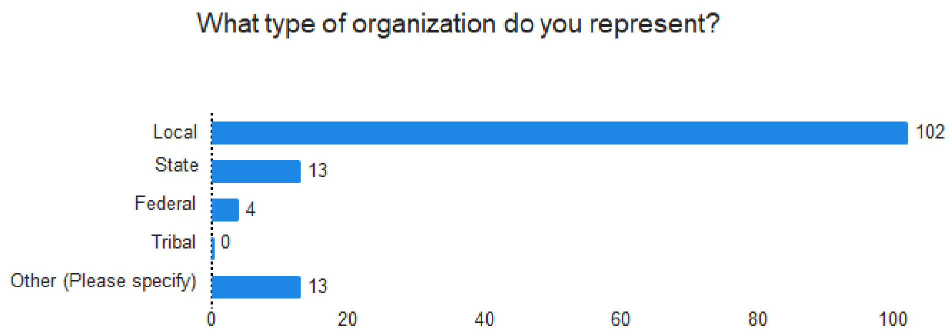

Figure 1. Organizations Represented.

Most respondents represent local organizations, indicating a substantial deployment at the community level. Most organizations reported having smaller fleets, typically 1-5 UAS units (Figure 2), suggesting that many agencies may be in the early stages of UAS adoption or face budget constraints. There are instances of larger fleets, indicating a more established use of UAS technology in some areas.

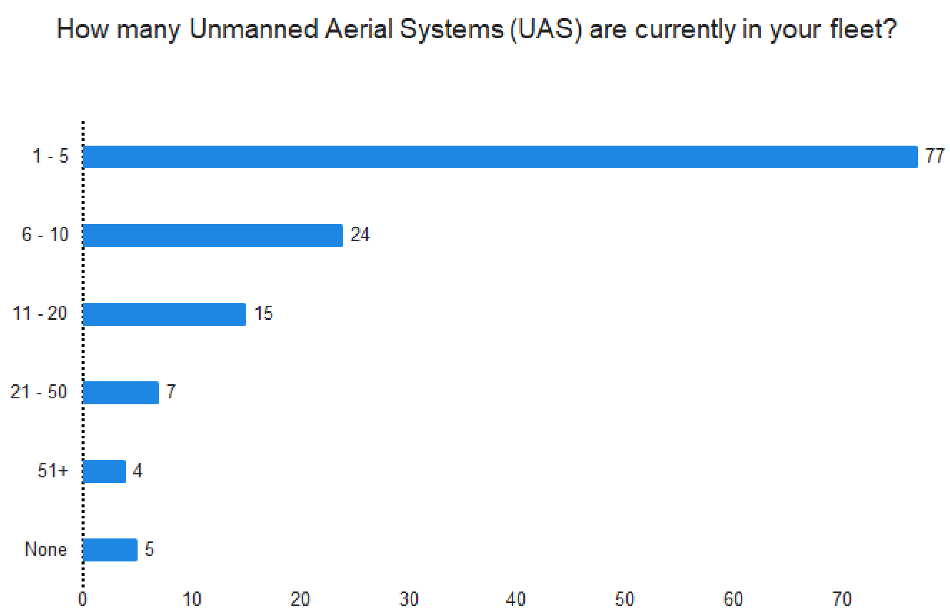

Figure 2. Number of UAS in Fleet.

Regarding the types of UAS employed, multirotor models dominate the fleets, accounting for nearly 90% of the survey responses (Figure 3). This preference likely stems from the versatility and ease of use that multirotor systems offer, especially their capability for vertical takeoff and landing, which is critical in disaster response scenarios. Fixed-wing and hybrid models are less prevalent, potentially indicating higher operating costs and complexities.

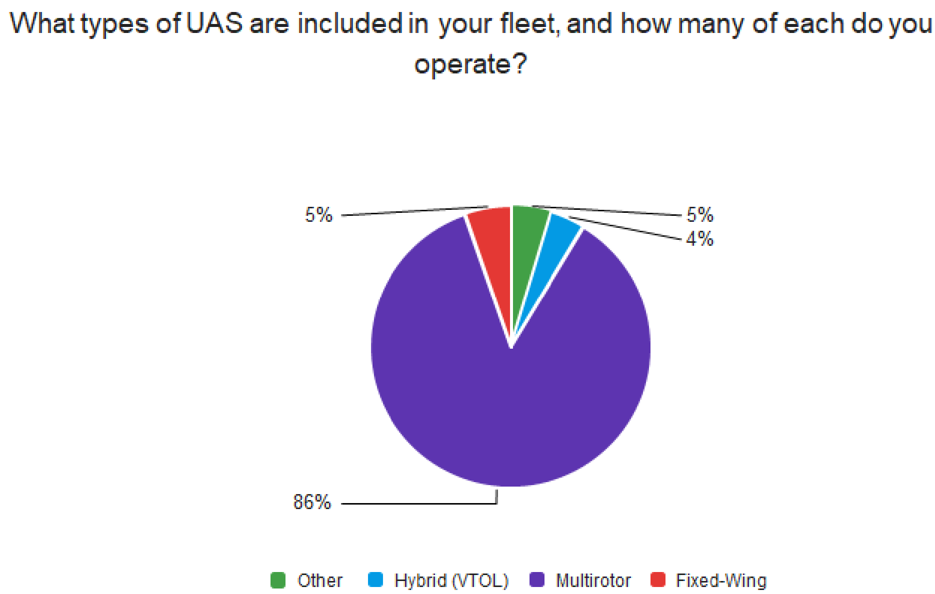

Figure 3. Fleet Composition.

Furthermore, the most common power source for these UAS is electric (battery), as shown in Figure 4. Less than 10% of UAS are operated by other sources of power. This indicates a high reliance on battery-powered UAS.

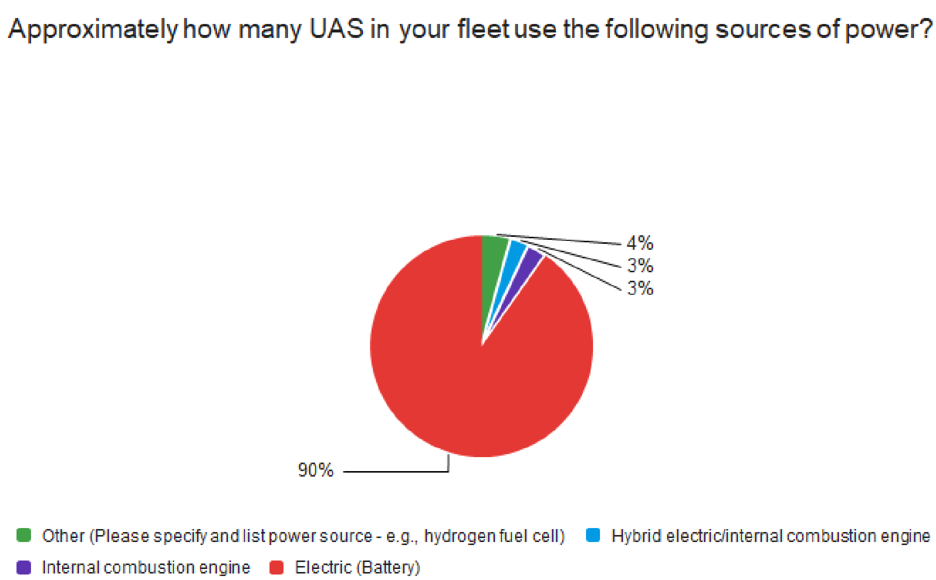

Figure 4. UAS Power Sources by Type.

The survey responses also provide insight into the types of sensors (Figure 5) and use cases (Figure 6) for these UAS. The most commonly used sensors include optical/visual cameras, Infrared (IR) cameras, and thermal cameras, which are essential for various applications, including search and rescue, damage assessment, surveillance, and monitoring. Deploying more specialized sensors like light detection and ranging and multispectral/hyperspectral cameras is less common but highlights advanced data collection and analysis potential. These capabilities underscore the critical role of UAS in providing situational awareness and supporting decision-making during emergencies.

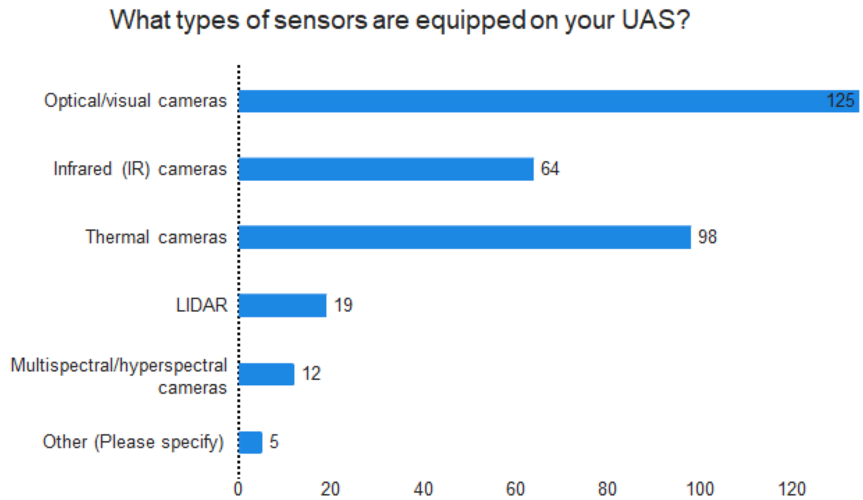

Figure 5. UAS Sensors.

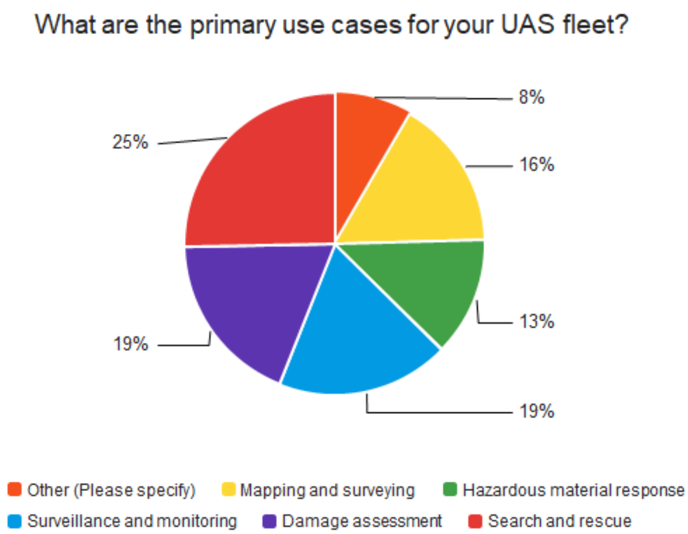

Figure 6. UAS Use Cases.

Fifty percent of organizations do not operate UAS that are certified under frameworks like Defense Innovation Unit (DIU)/Association for Uncrewed Vehicle Systems International (AUVSI) blue/green UAS (Figure 7). Only 21% of the UAS are under some certification framework. Notably, 29% of the data is unknown. This uncertainty suggests a gap in knowledge about UAS certification in general.

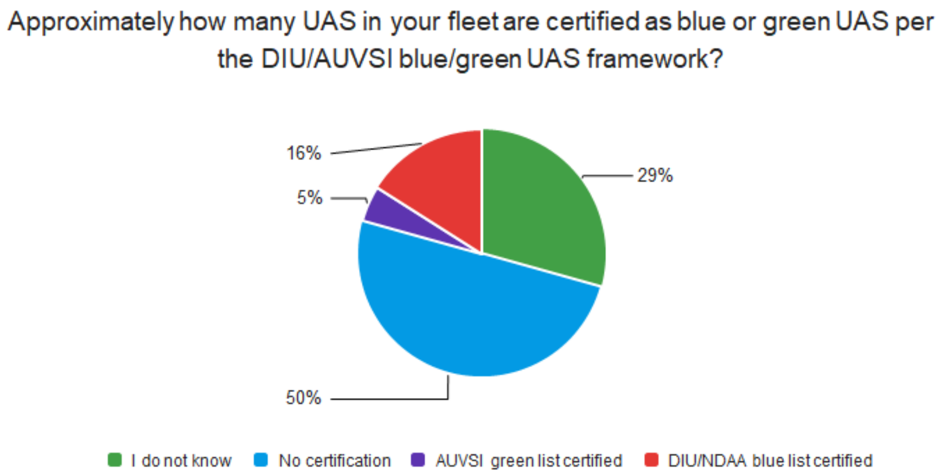

Figure 7. Blue/Green UAS Certification.

Most organizations have established policies and procedures for UAS operations with varying maturity levels (Figure 8). About 38% of respondents rate their policies as mature, tested, and validated, while 33% consider them somewhat mature. This variation suggests a need for further development and standardization. The most critical factors for UAS operations include reliable equipment, safety protocols, training requirements, data management and privacy, and interagency coordination. Regulatory compliance, maintenance, and logistics also rank highly, reflecting the complex operational landscape for UAS. Typically, these concepts are captured within detailed Standard Operating Procedures (SOPs) that reflect an organization's typical operational procedures and norms. While SOPs may differ somewhat from one organization to another, the fundamental concepts will likely remain the same. Appendix C contains an SOP template representing a means to standardize organizational operational procedures.

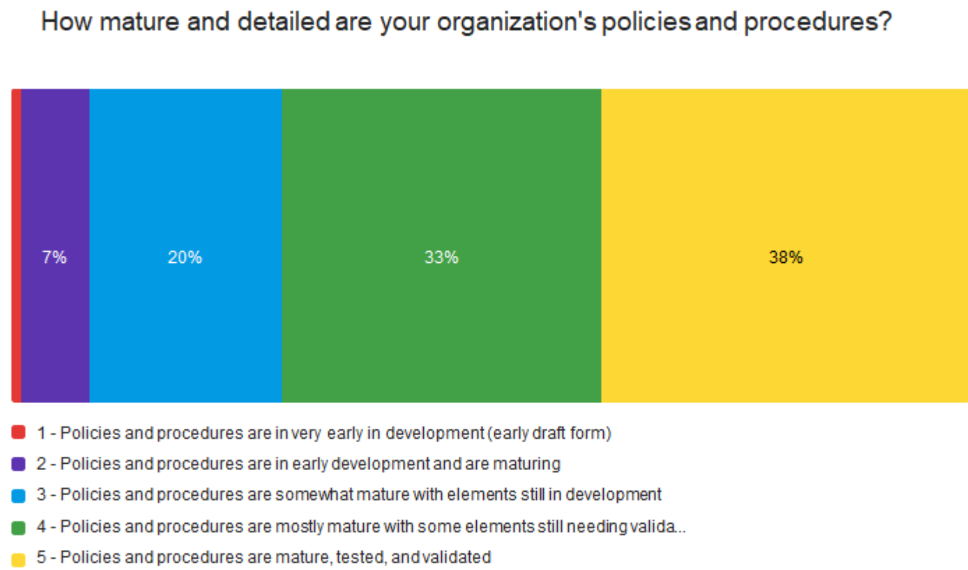

Figure 8. Maturity of Organizations Policies and Procedures.

Regular training is crucial, with 38% of organizations providing monthly training sessions (Figure 9). However, challenges such as budget constraints, lack of support from leadership, and the political environment around foreign-made UAS (e.g., DJI drones) present significant barriers.

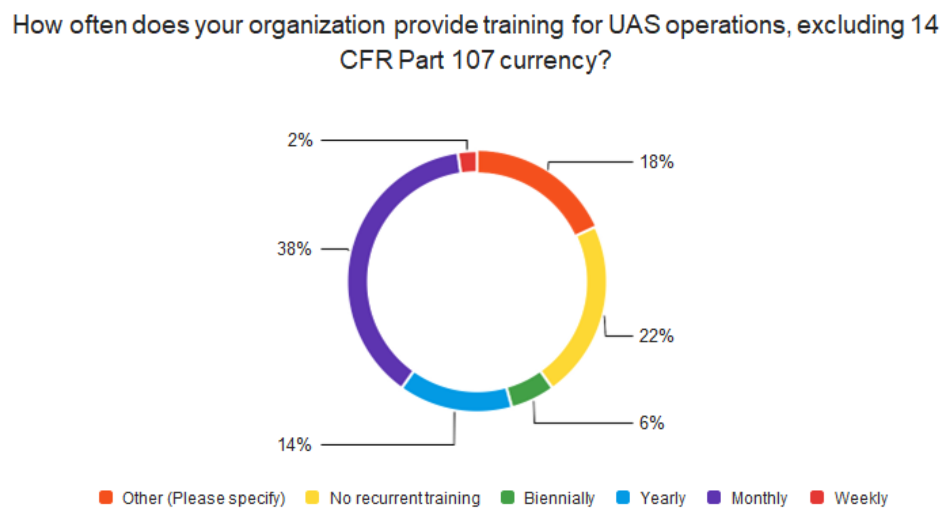

Figure 9. Respondent UAS Recurrent Training.

Maintenance procedures are in various stages of maturity (Figure 10), with 34% having somewhat mature procedures and 32% reporting mostly mature procedures. This diversity highlights the need for consistent and comprehensive maintenance protocols.

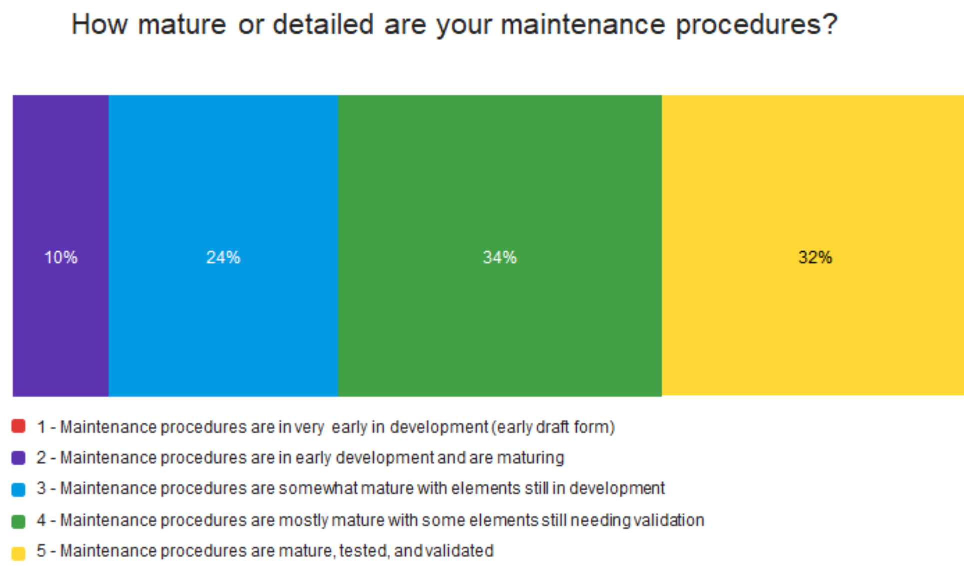

Figure 10. Maturity of Maintenance Procedures.

Figure 11 outlines key areas where organizations plan to focus their priorities. The expansion of fleet size is a priority for many organizations, driven by the need for increased operational capacity and capability. This expansion includes acquiring new types of UAS and enhancing existing fleets with advanced sensors and data analysis tools. Improving interagency collaboration and developing new use cases are also key focus areas. The need for better coordination and communication between agencies is evident, especially in complex disaster response scenarios. Training new pilots and enhancing existing pilot skills are critical, given the technical complexity of UAS operations and the high stakes involved in emergency response missions.

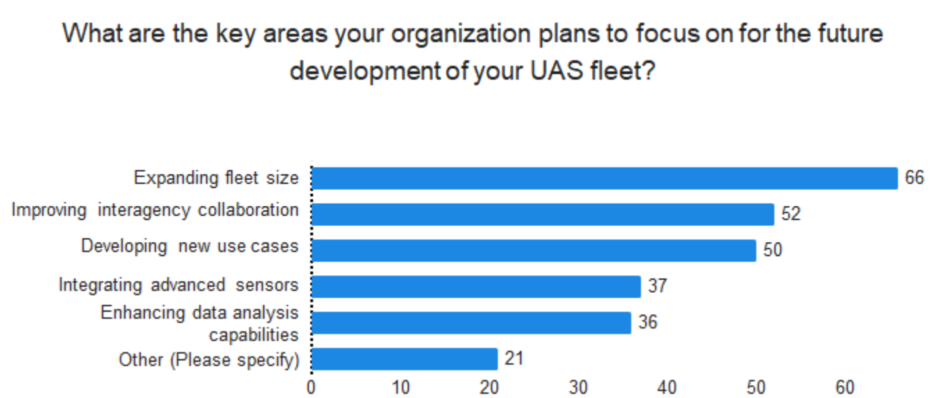

Figure 11. UAS Fleet and Program Priorities.

In conclusion, the survey results indicate a diverse and growing UAS fleet among public safety agencies, focusing strongly on multirotor systems powered by electric batteries. The primary use cases, such as search and rescue and damage assessment, highlight the essential role of UAS in emergency response. However, challenges remain in standardizing policies, ensuring regulatory compliance, and securing adequate funding and training. Organizations should prioritize expanding their fleets, enhancing interagency collaboration, and developing comprehensive training and maintenance protocols for future growth. Capturing these crucial items in core operational documents, such as detailed SOPs, will allow future growth and promote standardization. These steps will help ensure the effective and safe integration of UAS technology in disaster and emergency response efforts.

2.7 Sub-Task 4.7 – Determining UAS Typing Standards

A review of NWCG Standards for Wildland Fire Resource Typing PMS 200 – UAS Typing Standards and FEMA NIMS Resource Management Preparedness typing definitions and minimum capability standards was done to find common elements and gaps in the current typing standards. After the document review, the team discussed the findings with a member of NWCG. The team could not connect directly with FEMA, but the FEMA UAS Typing Standards are publicly available.

Current UAS typing standards for disaster response are structured frameworks that categorize UAS based on their capabilities, intended use, and sensor payloads. The following sections list the key elements that are included.

2.7.1.1 *FEMA UAS Typing Standards*

FEMA uses capability-based typing, as specified within Chapter 2 of FEMA's *National Incident Management System, Third Edition* (Department of Homeland Security, 2017). FEMA defines UAS types based on their capabilities, such as payload capacity, flight endurance, and sensor types. UAS are categorized by function, the aircraft platform such as aircraft-manned, aircraft unmanned, and the type, referring to capability and performance criteria.

2.7.1.2 *NWCG UAS Typing Standards*

NWCG uses performance-based criteria to define UAS types. These criteria define UAS types based on configuration, endurance, data collection altitude, max range, and typical sensors for each type. An example of this performance-based criteria is shown in Table 6.

Both FEMA and NWCG are aligned with their UAS typing standards. NWCG worked across agencies and with hundreds of first responders involved in flight operations in disaster response to develop current typing standards.

Table 6. Outline of Current UAS Typing Standards (National Wildfire Coordinating Group, p. 2, 2019).

Type	Configuration	Endurance	Data Collection Altitude (agl.)	Max Range (Miles)	Typical Sensors
1	Fixed-Wing Rotor Wing	6 – 14 hrs. N/A	3,500 – 8,000 N/A	50 N/A	EO/Mid Wave IR / High-Quality IR

2	Fixed-Wing Rotor Wing	1 – 6 hrs. N/A	3,500 – 6,000 N/A	25 N/A	EO/Long Wave IR / Moderate Quality IR
3	Fixed-Wing Rotor Wing	20 – 60 min. 20 – 60 min.	2,500 and Below 2,000 and Below	5 5	EO/IR Video and Stills Moderate Quality IR
4	Fixed-Wing Rotor Wing	Up to 30 min. Up to 20 min.	1,200 and Below 1,200 and Below	< 2 < 2	EO/IR Video and Stills Moderate Quality IR
Note: Certain aircraft are specialized and will not fit this classification. The table provides a genericized flight characteristic of altitude and endurance.					

UAS typing standards generally represent current UAS and payload systems in use today. As technology evolves, UAS typing standards will evolve as well.

2.8 Sub-Task 4.8 – Mitigating SGI Process Concerns

Operations under an SGI are considered advanced operations requiring additional certification or approval by the FAA (U.S. Senate, 1947). Operational approval for emergencies is amendments to existing COA or temporary endorsements to a Remote Pilot Certification to conduct specific operations, meaning specific times and locations. Applying for an SGI consists of sending a completed application to the FAA's System Operations Support Center (SOSC), where a representative must approve the request before operations may begin.

Public and civil UAS operations are eligible for SGI waivers when directly supporting governmental interests, including national defense, homeland security, law enforcement, and emergency operations (Federal Aviation Administration, 2023). Therefore, besides possessing an active COA or Part 107 Certificate, any SGI request must come from and be performed by a public entity or a civil operator sponsored by a public entity. Securing this sponsorship must take place before submitting an SGI request.

The primary concern of agencies responsible for disaster and emergency response and their civil partners is promptly receiving approval for SGI addendums. The range of anecdotal testimony regarding the quick turnaround time for SGI requests during emergency response efforts varies greatly. Some receive authorization in real-time, while other requesters experience hours of delayed operational support awaiting SGI deliberation. SGI approval is received quickly during larger-scale, coordinated events with active TFRs and where known authorities are agencies or agency partners performing operations. For example, is a longer duration TFR over a geographic area affected by a hurricane with federal Title X response efforts? The Air Operations Branch Director (AOBD) and the Air Tactical Group Supervisor (ATGS) determine the coordination, communication, and deconfliction protocols for airborne operations in the incident TFR. This includes denying UAS flight operations without an SGI in the TFR and verifying that the UAS operator requesting permission to fly within the TFR has received an approved SGI. A UAS operator must coordinate all flight operations within the established dispatch center, AOBD, and ATGS.

To reduce concerns over the SGI process, disaster and emergency preparedness agencies must prepare ahead of an incident. Identifying potential partners, operational qualifications, points of contact for FAA and other agencies, letters of agreement with civil partners, and defining the criteria for establishing a TFR on a case-by-case basis to facilitate smoother SGI coordination during emergency response. Anticipating potential barriers in non-emergency times with coordination amongst partner agencies and the FAA SOSC and incorporating the SGI process into training exercises may help alleviate the concerns for flight operations.

3 SUMMARY

This report summarizes the findings from ASSURE A62 Task 4 and associated sub-tasks. The research team explored topics relating to the core research questions listed in Section 1. The following sub-sections summarize research findings from each sub-task. These findings resulted from a detailed analysis of existing policy, literature review, and survey data collected from disaster response organizations.

3.1 Summary – Sub-Task 4.1

Sub-task 4.1 addressed the impacts of legislation that affects entities and organizations that use UAS for disaster response and recovery. The legislation with the most significant effect is the NDAA, particularly a component referred to as the American Drone Security Act of 2023. This legislation restricts government entities from procuring and operating UAS developed, manufactured, and sold from covered foreign entities, such as China and Iran. While these prohibitions have an exemption process, it is not always straightforward. This hampers responders' when procuring UAS that may meet their mission requirements. The American Drone Security Act of 2023 also calls for a study to identify gaps in the United States' ability to produce UAS domestically. The intent is to identify gaps and shortfalls in US capacity to acquire domestically produced UAS and determine methods to aid government entities in obtaining UAS compliant with existing laws and regulations.

3.2 Summary – Sub-Task 4.2

This sub-task addressed the concept of UAS training for public safety officials. This sub-task explored the application of notional public safety UAS ratings and certifications that offer unique skill sets relevant to disaster response and recovery operations. Findings from this task identify several benefits to specialized training. The most noteworthy finding is that specialized training would increase general competency in responders who use UAS for disaster response. Training emphasizing role-specific knowledge and practical skills may better prepare responders to use UAS for disaster response more effectively and safely.

This study also identified opportunities to continue standardization efforts for building UAS pilot skills and competencies. ASTM F3379 *Standard Guide for Training for Public Safety Remote*

Pilot of Unmanned Aircraft Systems (UAS) Endorsement represents an existing standard from which training guidance may be developed. It also represents an opportunity for responders to provide input to SDOs so that new remote pilot training and operational standards may be created to suit their needs.

Finally, this study identified the advantages of remote pilot training and the ability to obtain operations approvals and waivers – e.g., BVLOS, operations over people, etc. Remote pilot training may mitigate risk, leveraging demonstrated knowledge, skills, and abilities against operational risks. Standardized remote pilot training for responders may ensure that operational waivers and authorizations are more accessible and create fewer barriers to safe, effective disaster response operations.

3.3 Summary – Sub-Task 4.3

Building upon Sub-Task 4.2, Sub-Task 4.3 explores airworthiness qualifications and crew training for disaster response personnel. While Sub-Task 4.2 identified the impacts of UAS training for public safety and disaster response personnel, Sub-Task 4.3 went into greater detail to determine what those specific skill sets and procedures should be.

The research team explored airworthiness qualifications for public safety and disaster response UAS, identifying two primary approaches – standard and special airworthiness certificates. Neither of these approaches is viable for disaster response operations because a standard airworthiness certificate is only obtainable by the aircraft manufacturer with significant costs in time and capital, and a special airworthiness certificate often comes with very specific operational restrictions. The team also noted that different government organizations have airworthiness criteria, and many can self-declare their systems to be airworthy. A set of standard airworthiness criteria for disaster response UAS may be beneficial.

However, the research team notes that sUAS have no airworthiness requirements beyond being in a condition for safe flight. This often makes sUAS more flexible but does not leave them without their challenges. The biggest challenge for responders who wish to obtain a COA or authorization is demonstrating that their system is safe for the operational use case.

3.4 Summary – Sub-Task 4.4

While exploring mechanisms to mitigate against UAS incursions into airspace surrounding a disaster scene, the research team arrives at two primary categories to classify UAS incursions: ignorant/careless and nefarious. Addressing UAS operators that fall into one of these two categories provides responders with a better understanding of the scope of the problem and the best tools to address it.

Mitigating the effects of ignorant or careless remote pilots is primarily a matter of responders using the correct information and tools. 14 CFR §89 requires that all UAS sold in the United States are equipped with a means to broadcast a remote ID signal. This remote ID signal may alert responders engaged in disaster response and recovery to the presence of a nearby recreational UAS. This allows them to either take action to identify and address the remote pilot or take measures to remove the threat from the airspace by other means.

Addressing nefarious UAS operations presents a different challenge and represents a counter-UAS problem. While responders have many of the same tools available to them to address nefarious UAS as they do for an ignorant or careless hobbyist, these tools may not be effective against a remote pilot with nefarious intent. In these cases, responders may leverage counter-UAS solutions, taking a tiered approach to mitigate the air collision risk and locating the remote pilot responsible for the intruding aircraft.

3.5 Summary – Sub-Task 4.5

Standardizing practices for UAS operations supporting disaster response and recovery will require large-scale coordination at the national level. This is especially true if the desire for standardization extends from the federal level to smaller (local) departments and municipalities. Standardizing UAS operations for disaster response will require clear, detailed guidance that begins at the national level. This guidance may incorporate findings from previous sub-tasks in this research – e.g., crew training, strategies for mitigating UAS incursions, airworthiness standards, etc. Falling back on existing standards, such as those by ASTM International, NFPA, and NIST, offers a starting point to unify standard practices, procedures, and policies to ensure responders can use UAS effectively to respond to disaster events.

3.6 Summary – Sub-Task 4.6

Sub-Task 4.6 used a survey to identify trends in how different organizations and departments use UAS. This survey, found in Appendix B, identified common types and characteristics of UAS, sensors, and common challenges affecting various kinds of public safety organizations. This survey identified that most public safety entities use electric multirotor UAS and have relatively small fleet sizes. However, there are differences regarding the maturity of operational procedures and maintenance practices. A more detailed discussion of the survey data may be found in Section 2.6.

3.7 Summary – Sub-Task 4.7

The research team identified typing standards for UAS that fall into two primary categories – capability and performance-based. FEMA defines UAS categories by capability, and the NWCG uses capabilities as its standard. These typing standards allow UAS to be categorized by their primary capabilities and functions such that they may be allocated for disaster response. The research team found that FEMA and NWCG are primarily aligned with using their standards, and as UAS technology evolves, the typing standards will also evolve.

3.8 Summary – Sub-Task 4.8

Addressing and mitigating challenges associated with the SGI process is a significant concern for entities performing disaster response and recovery missions. While the SGI process is designed to enable government entities to gain operational approvals for UAS flight operations, the process may be unpredictable. Anecdotal testimony from responders identified mixed success with the SGI system, with some stating they received operational approvals in real-time. In contrast, others stated that their requests took several hours to process. Larger-scale disasters with established TFRs tended to receive swifter approvals. The variation in response times to SGIs forces responders to plan ahead, establish chains of communication and contacts within the FAA, establish letters of agreement with civil partners, and define criteria for establishing TFRs to save time.

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APPENDIX A: NIMS RESOURCE TYPING

A.1 – Small Unmanned Aircraft Systems (sUAS) Team

View Resource Typing Definition

RTLT

Small Unmanned Aircraft System (sUAS) Team

ID: 2-508-1246
Status: Published
Version: 2.0
Updated: 10/17/2023 12:35:37 PM
Original Release: 06/19/2018
Last Major Release: 10/17/2023
Resource Category: Incident Management

Core Capabilities

Primary: Situational Assessment
Secondary:
Supporting:

DESCRIPTION	A small Unmanned Aircraft System (sUAS) Team is comprised of a Remote Pilot in Command (Remote PIC) and a Technical Specialist – sUAS, an aircraft operations team without a human pilot onboard, also known as a drone. The Remote PIC holds a Remote Pilot Certificate for operating an sUAS and collecting data for improved situational awareness through remote sensing.
RESOURCE CATEGORY	Incident Management
RESOURCE KIND	Team
OVERALL FUNCTION	The sUAS Team: 1. Provides situational awareness by transmitting real-time or near real-time imagery, data, or verbal assessment, using multiple technologies, such as photogrammetry, live video, thermal imaging, and lidar, to enhance the Common Operating Picture (COP), planning functions, and Incident Action Plan (IAP) development 2. Uses various platforms based on mission need in accordance with Federal Aviation Administration (FAA) Code of Federal Regulations (CFR) Part 107, specifying sUAS
COMPOSITION AND ORDERING SPECIFICATIONS	1. Discuss logistics for deploying this team, such as security, communications, lodging, transportation, power, recharging, fuel, and meals, prior to deployment 2. Remote PIC determines the duty cycle of aircraft based on assignment, environment, terrain, battery life, and other factors affecting performance 3. Requestor should consider the following needs when ordering: a. Collection: A measurable description of each information or image collection task, including image resolution, and distribution instructions b. Processing: Ability to link platform to satellite, platform-required ground reception and range limitations, if any, data collection media used, delivery points of data on media, media compatibility with end users, and the turnaround time for analysis c. Distribution: Parameters for when, where, and how to disseminate images, information, and data d. Storage: Image, data, and information storage locations and servers and time frames for storage and maintenance 4. Requestor orders data analysis capabilities separately 5. Requestor and provider should discuss the capability requirements of the mission: a. Fixed wing sUAS that have short- to medium-range capabilities and are more agile b. Rotary wing sUAS that are very agile and can provide near-stationary monitoring but have limited flight times and altitudes c. Lighter-than-air sUAS that have extended flight times and can achieve significant altitudes but lack maneuverability and are more susceptible to weather than other UAS types 6. Requestor provides management and oversight of this team by: a. Providing Air Operations Branch staff, including the Air Tactical Group Supervisor and the Air Support Group Supervisor b. Ensuring Air Operations Branch staff understand UAS operations, FAA regulations, and requirements of other state, local, tribal, territorial, and federal agencies having jurisdiction 7. Requestor and provider should discuss availability of equipment and supplies needed to establish an adequate Ground Control Station, such as a portable system for data management, wireless or networking equipment, batteries, and a specialized communications cache. 8. Based on mission requirements, requestor and provider should discuss data collection payload options such as: a. Aerial photography b. Full motion video c. Specialized sensors, such as photogrammetry, sonar, radar, infrared, lidar, and hyperspectral d. Infrared thermography (IRT)

	9. Discuss mission planning factors, including: a. Time-on-scene and flight duration requirements b. Topography, climate, land and maritime factors, and population density c. Launch and retrieve capabilities; takeoff and line of sight capabilities; first-person view (FPV), beyond line-of-sight view, and video piloting; use of multiple controllers; and follow-me capability (electronic or tether) d. Operational time (day/night), takeoff and landing terrain, and operational area terrain e. Weather factors (maximum wind speeds, temperature, humidity, and inclement conditions) f. Airports and restricted airspace nearby 10. This team follows all applicable state, local, tribal, and territorial privacy laws and regulations 11. Requestor and provider should discuss the need for FAA waivers and authorizations, such as permission to fly beyond the visual line of sight, fly at night, fly directly over a person or people, fly multiple aircraft with only one pilot, fly above 400 feet, fly near airports, and fly in other restricted or special-use airspace 12. This team adheres to FAA restrictions on crew duty according to Title 14 CFR Part 117: Flight and Duty Limitations and Rest Requirements

Each type of resource builds on the qualifications of the type below it. For example, Type 1 qualifications include the qualifications in Type 2, plus an increase in capability. Type 1 is the highest qualification level.

Resource Typing Calculator: *To calculate a resource's type, select the cells below that are applicable to the resource. (Select the column header to choose an entire column.) The calculated resource type is displayed at the bottom of the screen.*

COMPONENT	TYPE 1	TYPE 2	NOTES
MINIMUM PERSONNEL PER TEAM	Same as Type 2	3	Not Specified
SUPPORT PERSONNEL PER TEAM	Same as Type 2	2 – National Incident Management System (NIMS) Type 1 Remote Pilot in Command 1 – NIMS Type 1 Technical Specialist–sUAS	1. Requestor provides Air Operations Branch staff for management and oversight of this team 2. Requestor ensures Air Operations Branch staff understand UAS operations and meet requirements of FAA, Federal Communications Commission (FCC), Department of Transportation (DOT), and other state, local, tribal, territorial, and federal agencies having jurisdiction 3. One PIC serves as a safety flight observer for the UAS Team during flight operations and is not in direct control of an operational UAS platform. The PIC provides field oversight and situational awareness, and ensures the safety of the PIC operating the UAS 4. Teams can add additional UAS aircraft and a corresponding number of additional PIC personnel within a manageable span of control 5. For Type 1 teams using UAS aircraft over 55 pounds, requestor should add pilots and personnel based on manufacturer recommendations for safe operation and handling.
AIRCRAFT SYSTEMS PER TEAM	Same as Type 2	Combination of fixed wing, lighter-than-air, and rotary wing sUAS aircraft that meet requirements under FAA Part 107	1. Requestor determines image resolution required using the National Imagery Interpretability Rating Scale (NIIRS) 2. sUAS platforms needed, such as fixed wing, rotary wing, or lighter-than-air, may vary based on mission assignment 3. For Type 1 and Type 2 teams,

			each sUAS should meet requirements under FAA Part 107
INFORMATION COLLECTION EQUIPMENT PER TEAM	Same as Type 2, PLUS: Specialized information collection equipment, such as: 1. Specialized sensors, such as photogrammetry, sonar, radar, infrared, lidar, and hyperspectral 2. Infrared thermography (IRT)	1. Photography 2. Full motion video	Requestor provides image resolution requirements based on mission needs.
COMMUNICATIONS EQUIPMENT PER TEAM MEMBER	Same as Type 2	1. Two-way portable radio 2. Cell phone	Consider alternate forms of communications, such as satellite phones, based on the mission assignment and team needs.

Notes

Nationally typed resources represent the minimum criteria for the associated component and capability.

References

1. FEMA, NIMS 509: Air Operations Branch Director
2. FEMA, NIMS 509: Air Tactical Group Supervisor
3. FEMA, NIMS 509: Air Support Group Supervisor
4. FEMA, NIMS 509: Remote Pilot-in-Command
5. FEMA, NIMS 509: Technical Specialist – Small Unmanned Aircraft System
6. FEMA, National Incident Management System (NIMS), October 2017
7. Federal Aviation Administration (FAA) Joint Order (JO) 7200.23: Air Traffic Organization Policy, October 2016
8. Title 14 Code of Federal Regulations (CFR) Part 107: Small Unmanned Aircraft Systems, latest edition adopted
9. Title 14 CFR Part 117: Flight and Duty Limitations and Rest Requirements, latest edition adopted
10. Department of Homeland Security Best Practices for Protecting Privacy, Civil Rights, and Civil Liberties in Unmanned Aircraft Systems Programs, December 2015

Published Versions

A.2 – Remote Pilot-in-Command (RPIC)

Administrator Log In

View Position Qualification

RTLT

Remote Pilot-In-Command

ID: 2-509-1381
Status: Published
Version: 2.0
Updated: 10/17/2023 12:36:01 PM
Original Release: 06/19/2018
Last Major Release: 10/17/2023
NQS Position: ☐
Resource Category: Incident Management

Core Capabilities

Primary: Situational Assessment
Secondary:
Supporting:

RESOURCE CATEGORY	Incident Management
RESOURCE KIND	Personnel
OVERALL FUNCTION	The Remote Pilot-in-Command (Remote PIC): 1. Holds a Remote Pilot Certificate with a small Unmanned Aircraft System (sUAS) rating and has the final authority and responsibility for the operation and safety of a small, unmanned aircraft operation conducted under Federal Aviation Administration (FAA) part 107 2. Operates a sUAS platform in a safe and secure manner according to all state, local, tribal, territorial, and federal regulations
COMPOSITION AND ORDERING SPECIFICATIONS	1. This position can be ordered as a single resource or in conjunction with a NIMS typed team (Small Unmanned Aircraft System Team). 2. Discuss logistics for deploying this position, such as working conditions, length of deployment, security, lodging, transportation, and meals, prior to deployment. 3. This position typically works 12 hours per shift, is self-sustainable for 72 hours, and is deployable up to 14 days.

Each type of resource builds on the qualifications of the type below it. For example, Type 1 qualifications include the qualifications in Type 2, plus an increase in capability. Type 1 is the highest qualification level.

Position Typing Calculator: *To calculate a position's type, select the cells below that are applicable to the position. (Select the column header to choose an entire column.) The calculated position type is displayed at the bottom of the screen.*

COMPONENT	SINGLE TYPE	NOTES
DESCRIPTION	The Remote PIC: 1. Operates the aircraft platform in a safe and secure manner according to all state, local, tribal, territorial, and federal regulations 2. Performs preflight and post-flight debriefings and safety checks of the aircraft platforms assigned to the team 3. Ensures safety for team members during flight 4. Develops mitigation measures to prevent unsafe acts 5. Communicates safety, hazards, needs, and concerns to the flight observer 6. Tracks flight activities 7. Ensures all members of the sUAS team are qualified in their position 8. Ensures completion and approval of appropriate documentation, such as flight waivers and activity logs 9. Communicates all mission and flight plans to the Air Operations Branch Director	Not Specified

EDUCATION	Not Specified	Not Specified
TRAINING	Completion of the following: 1. IS-100: Introduction to the Incident Command System, ICS-100 2. IS-200: Basic Incident Command System for Initial Response 3. IS-700: An Introduction to the National Incident Management System 4. IS-800: National Response Framework, An Introduction 5. Hazardous materials awareness training or equivalent, such as: a. Training in accordance with the Occupational Safety and Health Administration (OSHA) 29 Code of Federal Regulations (CFR) Part 1910.120: Hazardous Materials Awareness, OR b. IS-5.A: An Introduction to Hazardous Materials 6. Overview of Crew Resource Management (CRM)	Not Specified
EXPERIENCE	Knowledge: 1. Must provide the Authority Having Jurisdiction (AHJ) with training records showing Remote PIC competency in all relevant platforms 2. Must meet all current FAA Federal Aviation Requirements (FAR) for the Remote PIC position Experience: Must provide the AHJ with documentation of successful participation in a drill, functional or full-scale exercise, or incident within the past two years	AHJ may accept documentation of equivalent military experience.
PHYSICAL/MEDICAL FITNESS	1. Performs duties under moderate circumstances characterized by working consecutive 12-hour days under physical and emotional stress for sustained periods of time 2. Adheres to FAA restrictions on crew duty according to Title 14 CFR Part 117: Flight and Duty Limitations and Rest Requirements	Not Specified
CURRENCY	1. Functions in this position during an operational incident, exercise, drill, or simulation at least once every two years 2. Meets all current FAA FAR for the Remote PIC position	Not Specified
PROFESSIONAL AND TECHNICAL LICENSES AND CERTIFICATIONS	Certification in accordance with FAA CFR Part 107: sUAS	Remote PIC personnel must possess on their person a valid FAA certificate of licensure and government identification.

Notes

Nationally typed resources represent the minimum criteria for the associated component and capability.

References

1. FEMA, NIMS Guideline for the National Qualification System, November 2017
2. FEMA, NIMS 508: Unmanned Aircraft System Team
3. FEMA, NIMS 509: Technical Specialist–Unmanned Aircraft System
4. Federal Aviation Administration (FAA) Joint Order (JO) 7200.23: Air Traffic Organization Policy, October 2016
5. Title 14 Code of Federal Regulations (CFR) Part 107: Small Unmanned Aircraft Systems, latest edition adopted
6. Title 14 CFR Part 117: Flight and Duty Limitations and Rest Requirements, January 2017
7. OSHA 29 CFR Part 1910.120: Hazardous Materials Awareness, July 2019

Published Versions

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A.3 – Technical Specialist – Small Unmanned Aircraft Systems

View Position Qualification

RTLT

Technical Specialist - Small Unmanned Aircraft System

ID: 2-509-1382
Status: Published
Version: 2.0
Updated: 10/17/2023 12:36:33 PM
Original Release: 06/19/2018
Last Major Release: 10/17/2023
NQS Position: ☐
Resource Category: Incident Management

Core Capabilities

Primary: Situational Assessment
Secondary:
Supporting:

RESOURCE CATEGORY	Incident Management
RESOURCE KIND	Personnel
OVERALL FUNCTION	The Technical Specialist – small Unmanned Aircraft System (sUAS) provides technical support to the sUAS Team, including managing the data recording payload and software, managing communications systems and frequencies, and maintaining documentation in the appropriate chain of custody.
COMPOSITION AND ORDERING SPECIFICATIONS	1. This position can be ordered as a single resource or in conjunction with a NIMS typed team (Small Unmanned Aircraft System Team). 2. Discuss logistics for deploying this position, such as working conditions, length of deployment, security, lodging, transportation, and meals, prior to deployment. 3. This position typically works 12 hours per shift, is self-sustainable for 72 hours, and is deployable for up to 14 days.

Each type of resource builds on the qualifications of the type below it. For example, Type 1 qualifications include the qualifications in Type 2, plus an increase in capability. Type 1 is the highest qualification level.

Position Typing Calculator: *To calculate a position's type, select the cells below that are applicable to the position. (Select the column header to choose an entire column.) The calculated position type is displayed at the bottom of the screen.*

COMPONENT	SINGLE TYPE	NOTES
DESCRIPTION	The Technical Specialist: 1. Ensures that data recording and streaming payload is operational preflight, during flight, and post-flight to achieve the mission objectives 2. Communicates safety, hazards, needs, and concerns relating to data gathering and streaming payload to the flight observer 3. Maintains the flow of streamed data to the receiver while the aircraft is in flight 4. Ensures that backup recording payload are operational before launch 5. Checks that data is recorded, creates a backup copy, and forwards the original to designated operations, public information, and planning authorities 6. Documents the chain of custody for information gathered from the aircraft	Not Specified
EDUCATION	Not Specified	Not Specified
TRAINING	Completion of the following: 1. IS-100: Introduction to the Incident Command System, ICS-100 2. IS-200: Basic Incident Command System for Initial Response 3. IS-700: An Introduction to the National Incident	Not Specified

View Position Qualification

RTLT

Technical Specialist - Small Unmanned Aircraft System

ID: 2-509-1382
Status: Published
Version: 2.0
Updated: 10/17/2023 12:36:33 PM
Original Release: 06/19/2018
Last Major Release: 10/17/2023
NQS Position: ☐
Resource Category: Incident Management

Core Capabilities

Primary: Situational Assessment
Secondary:
Supporting:

RESOURCE CATEGORY	Incident Management
RESOURCE KIND	Personnel
OVERALL FUNCTION	The Technical Specialist – small Unmanned Aircraft System (sUAS) provides technical support to the sUAS Team, including managing the data recording payload and software, managing communications systems and frequencies, and maintaining documentation in the appropriate chain of custody.
COMPOSITION AND ORDERING SPECIFICATIONS	1. This position can be ordered as a single resource or in conjunction with a NIMS typed team (Small Unmanned Aircraft System Team). 2. Discuss logistics for deploying this position, such as working conditions, length of deployment, security, lodging, transportation, and meals, prior to deployment. 3. This position typically works 12 hours per shift, is self-sustainable for 72 hours, and is deployable for up to 14 days.

Each type of resource builds on the qualifications of the type below it. For example, Type 1 qualifications include the qualifications in Type 2, plus an increase in capability. Type 1 is the highest qualification level.

Position Typing Calculator: *To calculate a position's type, select the cells below that are applicable to the position. (Select the column header to choose an entire column.) The calculated position type is displayed at the bottom of the screen.*

COMPONENT	SINGLE TYPE	NOTES
DESCRIPTION	The Technical Specialist: 1. Ensures that data recording and streaming payload is operational preflight, during flight, and post-flight to achieve the mission objectives 2. Communicates safety, hazards, needs, and concerns relating to data gathering and streaming payload to the flight observer 3. Maintains the flow of streamed data to the receiver while the aircraft is in flight 4. Ensures that backup recording payload are operational before launch 5. Checks that data is recorded, creates a backup copy, and forwards the original to designated operations, public information, and planning authorities 6. Documents the chain of custody for information gathered from the aircraft	Not Specified
EDUCATION	Not Specified	Not Specified
TRAINING	Completion of the following: 1. IS-100: Introduction to the Incident Command System, ICS-100 2. IS-200: Basic Incident Command System for Initial Response 3. IS-700: An Introduction to the National Incident	Not Specified

APPENDIX B: UAS FLEET AND POLICY SURVEY QUESTIONS

Survey Summary: The Federal Aviation Administration (FAA) is conducting research to enhance its support for the public safety community during natural disaster responses through the use of Uncrewed Aircraft Systems (UAS). To gain insights into the current state of UAS programs, this survey has been created to gather key information about your UAS operations. The collected data will guide the development of regulatory policies and procedures to facilitate the future expansion of UAS fleets for disaster response across the nation.

1. **What type of organization do you represent?**
   - Local
   - State
   - Federal
   - Tribal
   - Other (please specify)

2. **How many RPICs are in your program?**
   - 1-5
   - 6-10
   - 11-20
   - 21-50
   - 51+

3. **How many Unmanned Aerial Systems (UAS) are currently in your fleet?**
   - 1-5
   - 6-10
   - 11-20
   - 21-50
   - 51+

4. **What types of UAS are included in your fleet and approximately how many of each? (Select all that apply)**
   - Fixed-wing
     - #
   - Multirotor
     - #
   - Hybrid (VTOL)
     - #
   - Other (please specify)
     - #

5. **Approximately how many UAS in your fleet use the following sources of power?**
   - Electric (battery): #

- Internal Combustion Engine: #
- Hybrid Electric/Internal Combustion: #
- Other: # (please specify)

6. **Approximately how many UAS in your fleet are certified as blue or green UAS per the DIU/AUVSI blue/green UAS framework?**
   - DIU/NDAA Blue List Certified: #
   - AUVSI Green List Certified: #
   - No Certification: #
   - Do not know

7. **What types of sensors are equipped on your UAS? (Select all that apply)**
   - Optical/Visual Cameras
   - Infrared (IR) Cameras
   - Thermal Cameras
   - Lidar
   - Multispectral/Hyperspectral Sensors
   - Other (please specify)

8. **What are the primary use cases for your UAS fleet? (Select all that apply)**
   - Search and Rescue
   - Damage Assessment
   - Surveillance and Monitoring
   - Hazardous Material Response
   - Mapping and Surveying
   - Other (please specify)

9. **On average, how often are your UAS deployed for disaster and emergency response missions each year?**
   - None
   - 1-5
   - 5-10
   - 10 or more

10. **Does your organization have established policies and procedures for UAS operations?**
    - Yes
      If "yes," how mature or detailed are your polices and procedures on a scale from 1 to 5 with 1 being new and 5 mature, tested, validated and true?
      - o 1, 2, 3, 4, 5
    - Do not have polices and procedures for UAS operations
    - In development

11. What do you consider most critical for an effective UAS response operation? (Rank in order of importance)

- Best and most reliable equipment
- Safety protocols
- Training requirements
- Data management and privacy
- Maintenance and logistics
- Interagency coordination
- Regulatory compliance
- Other (please specify)

12. How often does your organization provide training for UAS operators, excluding 14 CFR Part 107 currency?

- Weekly
- Monthly
- Yearly
- Biennially
- No recurrent training
- Other (please specify)

13. Does your organization have established maintenance procedures for its UAS fleet?

- Yes

  If "yes," how mature or detailed are your polices and procedures on a scale from 1 to 5 with 1 being new and 5 mature, tested, validated and true?

  - 1, 2, 3, 4, 5
- No
- In development

14. What are the primary challenges your organization faces with UAS operations? (Select all that apply)

- Regulatory restrictions
- Operational restrictions – e.g., limits on beyond visual line-of-sight flight
- Budget constraints
- Technical issues
- Training and skill development
- Interagency coordination
- Public perception and privacy concerns
- Other (please specify)

15. What are the key areas your organization plans to focus on for the future development of your UAS fleet? (Select all that apply)

- Expanding fleet size

- Integrating advanced sensors
- Enhancing data analysis capabilities
- Improving interagency collaboration
- Developing new use cases
- Other (please specify)

16. How would you describe how safety is integrated into your operations? (Select all that apply)
- Training
- Mission planning
- Mission/field briefs
- PPE
- Flight protocols and operations
- Emergency/contingency plans
- Other (please specify)

17. Have you experienced any operations or airspace conflicts during operations? (Check all that apply)
- Yes, crewed aircraft in the area
- Yes, other small or large UAS in the area
- Flight approval issues
- No
- Other (please specify)

18. (Optional) What are the biggest challenges you face with personnel, equipment, approvals, operations, or response using UAS?
- Open Text Box

19. (Optional) Is there anything you feel should be stressed in response with UAS?
- Open Text Box

20. (Optional) If there is one lesson learned through your previous operations, what is it and why?
- Open Text Box

APPENDIX C: STANDARD OPERATING PROCEDURES (SOP) TEMPLATE

SEE CORRESPONDING DOCUMENT

Appendix D. Task 5 Technical Research Report

A11L.UAS.68: Disaster Preparedness and Emergency Response Phase III

Task 5 Report: Investigation of Data Sharing and Storage Considerations

October 30, 2024

v 1.0

NOTICE

LEGAL DISCLAIMER

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1. Report No. A11L.UAS.68_A62	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle Disaster Preparedness and Emergency Response Phase III – Task 5 Report		**5. Report Date** October 31, 2024 **6. Performing Organization Code**
7. Author(s) Paige Brochu, https://orcid.org/0000-0001-8174-2273 Adam Zylka, https://orcid.org/0009-0009-7308-1271 Faine Greenwood, https://orcid.org/0000-0003-1514-4579		**8. Performing Organization Report No.**
9. Performing Organization Name and Address University of Vermont University of Alabama – Huntsville New Mexico State University North Carolina State University Kansas State University		**10. Work Unit No.** **11. Contract or Grant No.**
12. Sponsoring Agency Name and Address Federal Aviation Administration UAS COE PM: Karen Davis, ANG-C2 UAS COE Dep. PM: Hector Rea, ANG-C2		**13. Type of Report and Period Covered** Task Report (10/31/2024) **14. Sponsoring Agency Code** 5401 Federal Aviation Administration
15. Supplementary Notes		

16. Abstract

This research provides foundational concepts for a path forward when using UAS to collect data during a disaster or emergency situation. Data sharing and storage must be carefully considered as data is collected and used in an effort to assess damages and other needs and response efforts from coordinating agencies. There is a need for a central database that would include information of the UAS data collected during disasters including easy-to-use upload, search, and review tools.

17. Key Words UAS, sUAS, Emergency Response, Disaster Response, Recovery, Responder, Preparedness		**18. Distribution Statement** No restrictions.	
19. Security Classification (of this report) Unclassified	**20. Security Classification (of this page)** Unclassified	**21. No. of Pages** 33	**22. Price**

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TABLE OF ACRONYMS

CISA	Cybersecurity & Infrastructure Security Agency
DAART	Domestic Operations Awareness and Assessment Response Tool
DII	Demographically Identifiable Information
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Agency
GIS	Geographic Information System
LiDAR	Light Detection and Ranging
NGO	Non-Governmental Organization
NIST	National Institute of Standards and Technology
PII	Personally Identifiable Information
RPO	Recovery Point Objective
RTO	Recovery Time Objective
SGI	Special Governmental Interest
SOSC	System Operations Support Center
UAS	Unmanned Aircraft Systems

EXECUTIVE SUMMARY

The research conducted under this project is focused on the use of Unmanned Aircraft Systems (UAS) in emergency response scenarios. This report highlights key research findings around data sharing and storage considerations once UAS data has been collected. The team conducted a review of current strategies including real-world events in which UAS data was shared across institutions and organizations, and focus group meetings with local, state, and federal agencies to understand how UAS data has been shared and stored, and recommendations for future initiatives. The research team met with university emergency officials, the Vermont Agency of Transportation, the Vermont Center for Geographic Information, and the Federal Emergency Management Agency (FEMA) Region 1. These focus group meetings provided insight into the lessons learned and recommendations for data collection, sharing, and storage for future situations.

This report highlights key findings for the use of UAS during emergency situations. These findings include an identification of the types of UAS data preferred by FEMA and other disaster responders during disasters, criteria that can be used to determine if data collection is necessary or recommended in a given disaster situation, and specifications for training professionals to identify and mitigate potentially harmful Personally Identifiable Information (PII) in UAS-collected disaster data. These findings also include technical and operational requirements for the design of a central database of UAS-collected information for specific disaster incidents, as well as requirements for the design of a related database capable of storing up-to-date information on UAS hardware and software. Finally, the findings cover special cybersecurity considerations for UAS use for data collection during disasters, as well as suggested metrics for collecting and storing information about the nature and scale of UAS use during disaster response operations. This report's conclusions can be used as a framework for the development of UAS data sharing and storage systems that take into account the cybersecurity and privacy risks associated with UAS data collection for damage assessment during disasters.

1 INTRODUCTION & BACKGROUND

Since the Federal Aviation Administration's (FAA's) 14 Code of Federal Regulations Part 107 rule was finalized in 2016, opening American airspace to UAS flights for commercial and government purposes, these small aircraft have become a near-ubiquitous part of disaster response and recovery operations in the United States.

Today, UAS are used for a wide variety of data-collection purposes during disasters and emergencies, ranging from initial surveys of impacted areas, search and rescue overflights, mapping of impacted areas for damage assessment and rebuilding, pre-disaster risk assessment, and more. With UAS, aerial data can be collected very quickly after disasters at a low cost, hastening the speed of official disaster declarations and helping authorities gain situational awareness more quickly than was often possible in the past.

While UAS data collection during disasters has proven its value, considerable challenges still exist for disaster responders who wish to take advantage of it.

UAS flights over disasters must be carefully coordinated with other actors and other aircraft, and many UAS pilots who wish to assist with data collection efforts during disaster response operations may not fully understand how to use current systems that facilitate this coordination. They also may not understand why this coordination is necessary, which is a problem that has been highlighted by public media controversies over the grounding of certain UAS and crewed aircraft flights over areas impacted by Hurricane Helene.

UAS data collection teams – who may be comprised of volunteers, government employees, private company representatives, academic researchers, and public safety specialists - continue to struggle to communicate both with one another and with authorities during disaster response operations. In many cases, they continue to lack standardized or centralized tools for divvying up labor and prioritizing certain areas.

Currently, there is no standard centralized government repository tasked with storing UAS data collected during disaster events. In the absence of such a repository, UAS data collection teams often deliver their data to a wide range of different actors in an equally wide variety of ways, from sharing data on the cloud to physically handing USB data drives to intended recipients. This diffused approach presents difficulties for data users, who may not know where to look to find the information they need. It also presents considerable security and privacy risks, with poorly defined chains of custody for potentially sensitive information.

Although experts have made considerable progress in evaluating and understanding UAS cybersecurity risks in recent years, their analyses have rarely focused on the specific challenges presented by UAS data collection during disaster and emergency events. More specific research, case studies, and guidelines geared towards the unique needs of disaster responders are needed – guidelines that also keep in mind that the most secure UAS platforms may not be realistic options for many UAS data collection teams today, due to these platforms' cost and capabilities (or lack thereof).

At the same time, UAS data collectors and regulators are faced with a lack of clear guidelines and best practices for evaluating UAS data for the presence of personally identifiable information, as well as other potentially sensitive information. Such guidelines will need to be developed in tandem with the deployment of a centralized repository for UAS data, ensuring that this database does not inadvertently store unredacted sensitive information (such as images of deceased persons) – keeping in mind the imperfect nature of data security, and the constant threat of data breaches from both exterior and interior sources. The development of such guidelines is made more difficult by a notable lack of research and case study work examining how UAS data breaches can translate into harm.

Considerable gaps also exist in the collective understanding of what UAS are used by disaster responders and how they are used in practice during emergency events. Prospective buyers of UAS equipment for disaster response operations lack a single source of clear information on the capabilities of the products that they are considering and how these products have performed in real-world scenarios.

At the same time, no agency or organization is currently tasked with collecting operational data (based on clear metrics) concerning how UAS are used during emergencies, leaving analysts and researchers with little clarity into how UAS are used, what missions they are used for, what organizations use them, and the number and nature of accidents and incidents that take place during these response events.

While these challenges are considerable, they are surmountable. Working to address them will ensure that UAS data collection continues on its path to becoming an integral part of the American disaster response ecosystem.

1.1 Scope

The top-level research questions that defined the scope of this task include, but were not limited to, the following:

1. What would the requirements and implementation look like for a centralized interagency data portal to streamline cross-governmental coordination? What data sharing and storing principles can be incorporated that are currently practiced by federal agencies, such as the Domestic Operations Awareness and Assessment Response Tool (DAART) utilized by FEMA Region 4?
2. What are the cybersecurity risks associated with UAS supporting disaster and emergency response operations?
3. What are the requirements for a central database of UAS system and sensor capabilities, taking into consideration airworthiness and encryption factors? These capabilities should be based on standard test methods. Platforms should be vetted by real-world practitioners in the disaster and emergency response domain. An agency should be identified to host and maintain this database.
4. What metrics should be created for the use of UAS during disasters and emergencies? Examples include: Acquisition, maintenance, and operation costs, Percentage of UAS in aircraft fleet, number of UAS operations (by type of disaster), number of vehicle failures per platform during disaster response operations, number of operational failures per platform during disaster response operations, effective time of UAS operations (from planning to data delivery), frequency/tempo of UAS operations in an impacted area, and number and density of UAS operations in an impacted area, etc.

1.2 Objectives

The objective of this report is to outline requirements for centralized databases capable of recording anticipated UAS flight paths over disaster areas, storing and sharing UAS data collected during disaster, collecting up-to-date information on UAS system and sensor capabilities, and accumulating information (based on clearly defined metrics) about how UAS are used in practice during disaster response operations.

The following document will also discuss cybersecurity risks specific to disaster response operations and will define the development of best practices and tools for evaluating drone data collected during disasters for the presence of Personally Identifiable Information (PII) and other sensitive information.

2 RESEARCH FINDINGS

This portion of the document will provide answers to the A62 Task 5 research questions.

2.1 Requirements and Implementation for Centralized Interagency Data Portal

What would the requirements and implementation look like for a centralized interagency data portal to streamline cross-governmental coordination? What data sharing and storing principles can be incorporated that are currently practiced by federal agencies, such as the Domestic Operations Awareness and Assessment Response Tool (DAART) utilized by FEMA Region 4?

In the US, disaster and emergency responders are relying upon UAS-collected data more than ever before. However, despite the ever-growing popularity of UAS-collected data, there are still few standardized solutions, best practices, or data exchanges geared toward the needs of disaster responders and public safety.

In 2017, researchers with the Harvard Humanitarian Initiative found that UAS disaster responders, collecting aerial data during the responses to Hurricanes Harvey and Irma, reported regular challenges related to data management, storage, and utilization. In 2020 and 2021, researchers on the ASSURE A28 project surveyed fourteen organizations consisting of federal agencies, state agencies, volunteers, utility companies, software companies, and academics. Per analytical results compiled with Nvivo qualitative analysis software, the interviewees referred on numerous occasions to challenges related to data management and sharing.

Similar concerns from operational UAS users about the challenges of UAS data management came to light in a 2022 research report produced by UAS disaster response non-governmental organization WeRobotics, in which disaster responders in eight Eastern European countries were interviewed about their successes and challenges.

A centralized interagency portal for UAS collected data during disasters would address many of these challenges, providing all actors with a centralized, easy-to-use place to upload, search for, and review crucial aerial information. Additionally, this geospatial-data-focused database could streamline the FAA Special Governmental Interest (SGI) approval process for UAS operators, allowing actors to upload intended flight routes and other relevant information into a location where regulators can swiftly review them. The portal could also maintain lists of known, trusted UAS operators, further streamlining the emergency SGI approval process.

Key general considerations for this database should include:

Activation. The database should be opened to new submissions from UAS data collectors during emergencies and incidents. Entities and individuals should be able to follow an established, easy-to-use procedure to contact UAS database administrators to request the creation of a new data repository for a given emergency/incident.

UAS database administrators should be given the authority to determine if a request to activate the database is warranted or not, considering multiple criteria (including the size of the incident, the extent of the incident, the type of incident, the incident location, and so forth). Database administrators will be required to respond to requests in as timely a fashion as possible – preferably within less than 12 hours - and resources should be devoted to ensuring that this is the case.

Once a new incident or emergency data repository has been established, other UAS data collectors who wish to contribute data to the existing repository should be allowed to apply to submit via a procedure or form similar to that described above. Certain organizations that have used the database before may be permitted to utilize an accelerated authorization and repository creation process. New submissions to certain incidents or emergencies should be authorized for at least six months, ensuring that UAS imagery collected for early-stage reconstruction and recovery work can be incorporated into data repositories.

Outside of active emergency and incident response situations, authorized reviewers should be permitted to review previously collected data for certain analytical, research, and review purposes. Access to the database should be granted for a time-limited period (such as six months), and users will be required to re-apply to maintain access to archived datasets for analytical, research, and review purposes.

Functionality. The database should be deployed in a cloud environment and should be deployed and maintained to an industry-appropriate standard. It should be capable of storing and displaying *multiple types* of commonly collected UAS raster data, including photographs, videos, and processed orthomosaics (typically in GeoTIFF format). The database could potentially be expanded to accommodate the storage of other common forms of UAS-collected data, such as Light Detection and Ranging (LiDAR)-derived elevation data and 3D models. The database should also be capable of storing and displaying UAS flight path vector data, preferably in KML/KMZ and shapefile formats.

Reliability. The database must be highly reliable and should provide 99.9% availability. The upload process should be as reliable as possible and should be designed to accommodate disaster scenarios in which broadband connectivity may be spotty or slow. The database must be capable of quickly loading UAS-collected data for the end user, minimizing lag and friction.

Searchability. The database should be readily searchable, permitting authorized reviewers to look for UAS data on the basis of discrete disaster events, disaster types, data types, dates, and geographic locations. Users should be able to conduct searches both via a visual geospatial user interface and text queries. The database should be designed in such a way that each uploaded item (image) has metadata attached to it containing searchable, relevant information, including the date of collection, the time of collection, the name of the organization or individual conducting collection, and the UAS type and sensor used, text-based notes added by the uploader, and other key information.

The database should adhere to clearly defined metadata standards, based on the North American Profile of ISO19115:2003 - Geographic information 2003 (ISO 19115 NAP). Additional metadata requirements should be developed on a collaborative basis with the input of ASSURE members. Developers should also consider producing a database product that adheres to the open-source STAC Specification for describing and cataloging spatiotemporal assets.

Ease of use. The database must be easy to use, and user experience testing should be conducted before it is released. Clear documentation must be provided, as well as online/on-demand training materials for new users. It should not be assumed that UAS data collectors are familiar with common Geographic Information System (GIS) software platforms or possess GIS skills.

Interactivity. The database's display layer should make it easy for approved users to view multiple UAS data products in different layers on a single web map, allowing them to quickly compare these data products to each other. The display layer should make it easy for viewers to compare the UAS data to other sources of remotely-sensed information held by the federal government, such as the satellite, aerial imagery, and LiDAR imagery hosted by the United States Geological Survey Earth Explorer data portal.

Users should be able to easily compare UAS and certain external imagery captured on different dates and at different times via "swipe" tools, timeline tools, or similar tools built into the data-viewer user interface. When users click upon a certain geographically-mapped data point pertaining to an individual photograph or video, the user interface should display the video or image in a sidebar.

The data viewer should permit authorized users to add vector features (such as boxes, arrows, or other symbols) as a new layer over the data, which they can then authorize other selected viewers to see. Users should also be able to drop a pin on a given location to which they can add text-based notes, which can be shared with other users if desired. It should be possible for authorized users to export these datasets into KML or Shapefile file formats. These interactive tools will help users collectively make sense of UAS-collected data in the immediate aftermath of a disaster.

This interactive and comparative data capability will be extremely useful to disaster responders, GIS analysts, and other parties attempting to quickly visually determine how a disaster has impacted a certain area. Approved users should be permitted to use image and map services hosted by the database to produce their own web-based applications and tools for analytical work.

Security. The database must be highly secure and must adhere to well-known cybersecurity standards (listed in detail below). Database users should be required to review security and privacy protection guidelines before using the database and should be given "just in time" training in these areas during active disaster response scenarios. When disasters are not taking place, UAS users who anticipate contributing to the database in the future should complete more detailed training on these topics. The database must be designed in such a way that certain data can be securely concealed from certain users when deemed appropriate by administrators

Privacy protection. The database must include a standardized procedure for reviewing submitted data to ensure that it does not contain sensitive information (such as images of deceased or injured individuals), as well as personally identifiable information. This review process should *not* be left up to the discretion of the UAS data uploader: secondary review must take place before data is released to wider audiences. This review process will be designed to ensure that it can be completed as quickly as possible, keeping in mind the importance of swiftly-available data during disaster response operations. Recommendations for the development of such a procedure will be described in Section 2.5 of this document.

External Integration. The UAS database should be interoperable with other GIS-based tools and information dashboards, such as FEMA's Search and Rescue Common Operating Platform and Geospatial Damage Assessments tools. It should be possible for these external services to utilize geospatial data hosted by the database, such as orthomosaics and feature layers containing points and still photographs. Data sharing to external sources must be dependent upon review of the data for potential PII and other security issues: data uploaders must give their consent before external sharing can take place.

2.1.1 Facilitating UAS Disaster Response Communication and Flight Approvals

Beyond data storage, the centralized interagency data portal/database could facilitate communication between multiple actors, including UAS operators, the FAA's System Operations Support Center (SOSC), other disaster responders, and state agencies during the course of disaster events.

Such a system could also provide both UAS disaster responders and the FAA's SOSC with a more centralized, efficient alternative to the existing SGI process of approval.

These communication and approval functions would include:

- Provision of a centralized location for state agencies to submit letters of support/tasking for UAS data collection services from other entities, such as universities, private companies, and non-governmental organizations.
- Storage and hosting for authorized external use of geospatial (KML/KMZ/shapefile) information (accompanied by a written narrative) about when, where, and why UAS disaster responders intend to operate their aircraft during disaster, allowing the FAA's SOSC and other actors to quickly review and approve proposed flight plans as part of the SGI process.
- For discrete disaster events, provision of a shared spreadsheet or other standardized data sharing platform for all responding UAS operators, allowing them to quickly coordinate their efforts on an hour-to-hour basis and share information about their technical capabilities and available aircraft (as inspired by a similar shared spreadsheet set up by the University of Vermont Spatial Analysis Lab for other Vermont UAS actors to use during the July 2023 flooding event).

2.1.2 Functional Requirements

The following list of general requirements for such a centralized interagency data portal overlap with but are not identical to those developed to address A62 Task 9: Data Collector and Database Development (which can be reviewed in the report entitled *A11L.UAS.68 Disaster Preparedness and Emergency Response Phase III: Data Exchange Requirements Document for Database*).

A template for how such a system might be designed is provided in A11L.UAS.68: Disaster Preparedness and Emergency Response Phase III: Data Management Plan for Flight Events.

2.1.2.1 General

[ASSURE-DB-1] The database must be deployed in a cloud environment.

[ASSURE-DB-2] The database must provide industry-standard service methods to support data exchange between public safety users.

2.1.2.2 Database

[ASSURE-DB-3] The database must store the data collected from flight events in a cloud database.

[ASSURE-DB-4] The database must provide 99.99 percent availability.

[ASSURE-DB-5] The database must be monitored for performance degradation.

[ASSURE-DB-6] The database resource capacity must be able to scale as user demand increases.

2.1.2.3 Flight Coordination

[ASSURE-DB-7] The database must allow authorized users to upload KML/KMZ/Shapefile vector data depicting areas of intended flight operation, linked to a given disaster or emergency event. These data entries must include fields for a written descriptive narrative, the name of the submitter, the proposed start and end dates of flight, and other relevant information.

[ASSURE-DB-8] The database must allow authorized users to review these KML/KMZ/Shapefiles of intended flight operation.

[ASSURE-DB-9] The database/portal must have a mechanism for storing lists of trusted/approved UAS operators for each given state or region.

2.1.2.4 Data Collection

[ASSURE-DB-10] The database must store files recorded.

[ASSURE-DB-11] The database must be capable of storing multiple forms of data in multiple formats commonly used in disaster and emergency response drone data collection operations, including photographs, videos, and processed orthomosaic images.

[ASSURE-DB-12] All uploaded data artifacts must have relevant metadata appended to them, including *but not limited to* date of collection, time of collection, geographic area of collection, data type, sensor type, and other relevant fields.

[ASSURE-DB-13] The database must record metadata for UAS collected information in accordance with the North American Profile of ISO19115:2003 - Geographic information – Metadata standard.

[ASSURE-DB-14] Additional metadata standards must be developed collaboratively by ASSURE members.

[ASSURE-DB-15] The database must be as easy to use as possible, for both data uploaders and for data viewers/"customers."

[ASSURE-DB-16] User interface design must consider qualitative feedback from prospective end-users.

2.1.2.5 Data Persistence

[ASSURE-DB-17] All data stored in the cloud must remain available unless otherwise requested to be archived or removed.

[ASSURE-DB-18] There should be a clearly defined, standardized procedure by which concerned parties can request that data be removed.

2.1.2.6 Data Storage and Backup

[ASSURE-DB-19] Daily database backups must be taken and kept for a minimum of 7 days.

[ASSURE-DB-20] The Recovery Point Objective (RPO) must be within 1 hour.

[ASSURE-DB-21] The Recovery Time Objective (RTO) must be within 12 hours.

[ASSURE-DB-22] Backups must be monitored for failures to ensure the RTO and RPO targets.

2.1.2.7 Users

[ASSURE-DB-23] Database users who require elevated privileges to perform administrative-level duties must be authorized administrators.

[ASSURE-DB-24] Database users who need to run reports must be restricted to read/write permissions.

[ASSURE-DB-25] Database users must adhere to the principle of least privilege best practices.

[ASSURE-DB-26] Database user passwords must be at least eight characters long.

[ASSURE-DB-27] The password must contain characters from three of the following four categories: English uppercase letters, English lowercase letters, numbers (0-9), and non-alphanumeric characters (!, $, #, %, etc.).

2.1.2.8 Data Management

[ASSURE-DB-28] Structured data must be in CSV and Parquet file formats for compatibility with the cloud object storage.

[ASSURE-DB-29] The data in object storage must be kept unless otherwise requested by the customer.

[ASSURE-DB-30] Data must be made available through a cloud reporting service.

[ASSURE-DB-31] Direct access to the data must not be made available to end users.

[ASSURE-DB-32] Users may be permitted to download certain datasets in certain formats (such as GeoTIFF files) when deemed appropriate by Data Managers.

[ASSURE-DB-33] PII and other sensitive information must not be stored.

[ASSURE-DB-34] The data management team must develop and utilize a standardized review process to evaluate incoming data to ensure that it does not contain PII or other sensitive information.

[ASSURE-DB-35] The data management team must develop and utilize a standardized process for securely redacting data that contains sensitive information, in circumstances where this is deemed to be appropriate. The criteria for deeming such a circumstance appropriate must also be clearly defined.

[ASSURE-DB-36] Data storage devices must be redundant and able to tolerate failures.

2.1.2.9 Data Visualization and Reporting

[ASSURE-DB-37] The presentation layer must be delivered through a cloud reporting service.

[ASSURE-DB-38] Users should be able to easily search for data (when permitted to do so) using metadata tags, including date of collection, time of collection, geographic area of collection, data type, sensor type, and other relevant information.

[ASSURE-DB-39] The presentation layer should load as quickly in the browser as is realistic, ensuring that it can be viewed even when the user lacks access to a high-quality Internet connection.

[ASSURE-DB-40] The presentation layer should be easy-to-use and easy-to-navigate and should be presented in the web browser in a familiar web-map style.

[ASSURE-DB-41] The presentation layer should allow users to view multiple data sources at once on the same map, permitting them to visually compare and contrast these items in the browser.

[ASSURE-DB-42] The presentation layer should allow users to view other data sources from other government GIS repositories when possible, permitting these to be readily compared to collected UAS data.

2.1.3 Data and Information Requirements

2.1.3.1 Data Governance

Data governance fosters a common vision of data-related practices and promotes more effective use of data. It improves understanding of the data collected, reported, and used by program areas and the organization. As a result, the policy promotes more consistent, efficient, and coordinated responses to data issues and enhances communication and collaboration among program, technology, and other staff.

Note: The data management team will mostly be comprised of ASSURE team members and will be further defined in future documents.

[ASSURE-DB-43] The data management team must determine which users must have access to the systems that pertain to their areas.

[ASSURE-DB-44] The data management team must determine who is granted access to which data and at what granularity within the system.

[ASSURE-DB-45] Requests for access to data must be reviewed by the data management team in coordination with the customer.

[ASSURE-DB-46] Any changes to data collection must be reviewed by the data management team to determine the impact and level of effort.

[ASSURE-DB-47] Data must be released through cloud reporting services.

2.1.4 Performance Requirements

2.1.4.1 Database Performance

[ASSURE-DB-48] Performance must be monitored for the cloud database reports.

2.1.4.2 Data collector Performance

[ASSURE-DB-49] The data collector processes must provide near real-time data transfer performance.

2.1.5 Security Requirements

2.1.5.1 Database Compliance Standards

The database must comply with the following security standards: International Organization for Standardization 27001, System and Organization Controls 2, Federal Risk and Authorization Management Program, National Institute of Standards and Technology (NIST) 800-53, and Cloud Security Alliance Security, Trust, Assurance, and Risk. These standards will ensure that the database is designed, implemented, and maintained with security as the primary consideration, providing robust protection for the confidentiality, integrity, and availability of data.

2.1.5.2 Information System Security Requirements

[ASSURE-DB-50] Data must be kept confidential and made available to only authorized parties.

[ASSURE-DB-51] Data integrity must be preserved and not tampered with after submission.

[ASSURE-DB-52] If submitted data is found to contain personally identifiable information or other information deemed to be problematic, it should only be redacted or removed by means of a clearly defined process.

[ASSURE-DB-53] Records of actions taken to remove or redact data due to PII and security concerns should be maintained.

[ASSURE-DB-54] The database must be made available to users with resiliency against various types of failures.

2.1.6 Quality and Configuration Management Requirements

2.1.6.1 Quality Assurance

[ASSURE-DB-55] The database MUST comply with FAA-STD-016A, Quality Control System Requirements.

2.1.6.2 Configuration Management

[ASSURE-DB-56] Versions of the schema and the changes to the objects must be tracked.

[ASSURE-DB-57] Changes to data collection must also be documented, and a formal review process must be established.

2.1.7 Test and Evaluation Requirements

2.1.7.1 Development Testing

[ASSURE-DB-58] The database must comply with developmental acceptance tests to demonstrate the successful creation of a cloud database.

[ASSURE-DB-59] The database must comply with developmental acceptance tests to demonstrate a successful creation of a schema within the cloud database.

[ASSURE-DB-60] The database must comply with developmental acceptance tests to demonstrate a successful importing of data from object storage file sources into the cloud database.

2.1.7.2 Operation Testing

[ASSURE-DB-61 The database must comply with operational acceptance tests to demonstrate all functional, data, and performance requirements are satisfied.

2.2 Cybersecurity Risks Associated With UAS Supporting Disaster and Emergency Response Operations

What are the cybersecurity risks associated with UAS supporting disaster and emergency response operations?

The growing use of UAS in disaster and emergency response operations invites a new set of cybersecurity risks. It is of vital importance that disaster responders be made aware of these risks – and provided with the tools they need to identify and counter them.

In 2022, researchers with ASSURE published "UAS Cyber Security and Safety Literature Review," a comprehensive document which reviewed over 550 academic articles and identified 31 potential cybersecurity threats to small (<55 LBS; Group 1 and Group 2) UAS. These were then categorized into five groups pertinent to different components of the UAS ecosystem: UAS hardware, UAS software, network, ground control station, and cloud/server backend. This research project also identified and reviewed commercially available UAS platforms and custom-build kits, identified UAS cases across industries, and assessed cybersecurity threats to those use cases.

The discussion in this document will refer to this prior work. The majority of the findings and guidance described in the prior document are highly relevant to disaster response efforts and do not need to be repeated in detail here. However, some special, additional considerations must be taken into account during UAS data collection operations during disaster, which will be addressed in the following sections.

2.2.1.1 Special Considerations for Security and Cybersecurity during Disaster

Response operations carried out by the government and by other organizations almost inevitably entail the collection and storage of large amounts of data about impacted individuals. This data can be immensely helpful to individuals and communities in need; however, it is also incumbent upon those who steward this data to protect it. Disaster responders must adhere to best practices for cybersecurity, data protection, and data minimization to ensure that their efforts do not inadvertently harm the people they are trying to help.

As UAS data collection becomes a routine part of disaster and emergency response operations, disaster responders need a clear understanding of the risks that accompany these efforts. They should, in advance of initiating data collection efforts, consider these questions:

- Does this data absolutely need to be collected to achieve a certain aim? The most secure data is data that is never collected. If data exists, it can be compromised or stolen.
- Who will be using this data? What are their cybersecurity practices?
- Will the data be used for purposes other than those intended during initial collection? Community members may be concerned that data collected during disaster response may be shared with parties beyond disaster responders.
- How could this data be used by bad actors? Who might the most likely bad actors be?
- How long will this data be stored? The risks and benefits of storing data versus deleting it (in the interest of protecting it from being compromised) must be carefully weighed.
- Is there a protocol in place for reviewing data for potential privacy/PII risks? (Refer to Section 2.5 of this document).

- Are data collectors aware of cybersecurity risks? Have they been trained? Do they have a clear understanding of potential risks? Have background checks been performed?
- If there is a cybersecurity breach, is there a process in place for alerting individuals and communities whose data may have been impacted?

2.2.1.1.1 Preparing Before Disaster

Disaster response operations inherently require deployment on short notice. UAS pilots and UAS data users must be familiar with cybersecurity and privacy protection topics before disaster response efforts actually take place. Training on cybersecurity and privacy must be a vital part of UAS training programs, ensuring that everyone is on the same page and knows what to do.

UAS systems and devices that interact with UAS must be kept in a secure, well-monitored location when not in use. Specific personnel must be responsible for regularly updating UAS and device software, ensuring that it can safely be used when disasters take place. Devices should be constantly monitored for signs of remote access, viruses, or other dangerous activity.

Secure passwords must be used for all devices.

2.2.1.1.2 Limited Connectivity

Connectivity may be limited during disasters, and UAS users may not pay as much attention as they should to secure practices for transmitting UAS data.

UAS pilots and data users should be required to use a VPN when transmitting UAS data via wireless networks. All smart devices used with UAS platforms, such as smartphones, tablets, and computers, should also be equipped with a VPN.

2.2.1.1.3 Chaotic Environments

During disasters, it is understandably challenging to maintain the level of organization and control over people and equipment that is possible under normal conditions. These conditions create opportunities for bad actors to access UAS platforms or UAS data without being noticed.

All individuals who interact with UAS platforms during operational missions should be carefully vetted. When possible, background checks should be applied. The risk of data theft or misuse by internal actors – who may have personal connections within communities where data collection is taking place - should be carefully considered.

UAS equipment and data must be stored in a secure, well-attended location during disaster response operations; unauthorized individuals should not be given the opportunity to tamper with equipment.

UAS data should be encrypted whenever possible. Some UAS provide SD card encryption and other secure features. On UAS without these features, UAS data should be encrypted as soon as it is offloaded onto a secondary device.

UAS data should not be stored or viewed on unsecured computers, laptops, or smart devices.

UAS pilots should never be permitted to use personal devices, such as computers or smartphones, to connect with UAS platforms and equipment.

2.2.1.2 Balancing Security with Accessibility

Since 2013, small UAS have become much more affordable and much easier to use, a market development that enabled many governments, disaster response organizations, and volunteer organizations to begin using them for data collection during disasters and emergencies.

Many of these small UAS platforms are manufactured in China, including those produced by DJI, the largest consumer UAS company in the world. Currently, there is considerable US government concern about cybersecurity risks associated with Chinese-made small UAS. A 2024 Cybersecurity & Infrastructure Security Agency (CISA) document ("Cybersecurity Guidance: Chinese-Manufactured UAS") advises that organizations procure secure-by-design systems that are compliant with federal cybersecurity policies, which are listed in the Department of Defense Blue UAS Cleared List.

While these recommendations are very reasonable, it is important to note that at the time of writing, Blue UAS systems are offered at a considerably higher price point than that of Chinese-made systems. Disaster response organizations, which often operate with limited budgets, may not be able to afford compliant Blue UAS equipment; additionally, they may not be able to afford to substitute these systems for the Chinese-made UAS they already have.

The current list of Blue UAS systems is also heavily geared towards security and military applications for UAS. Many of the currently listed systems are not well-suited for common disaster response use cases like the production of high-resolution orthomosaic images for damage assessment (a task that requires a UAS platform with RTK capabilities for high-accuracy mapping results, which few Blue UAS platforms currently offer).

In light of these considerations, it is crucial to weigh cybersecurity considerations against realistic expectations for organizations and their current UAS fleets.

It should be assumed that many organizations collecting data during disasters will be flying Chinese-made UAS platforms. In many cases, rejecting data collection by Chinese-made UAS platforms will result in no UAS data being collected at all during a given event.

Officials should evaluate disaster situations and emergencies on a case-by-case basis. While certain extremely sensitive incidents or areas may warrant barring UAS data collection by Chinese-made systems, many (indeed, most) will not.

UAS users who use Chinese-made platforms should be encouraged to follow CISA cybersecurity guidance, including recommendations related to ensuring that software and firmware versions are installed before operational use, removing and securing SD cards from UAS before storage, avoiding broadcasting or live-streaming on the public internet during sensitive operations, and other considerations.

Disaster responders need better access to UAS systems that are affordable, capable of making high-quality maps, and that are compliant with federal cybersecurity policies and best practices. Government effort and funding should be directed towards working with manufacturers, both in the US and elsewhere, to produce UAS systems that better meet these specific needs.

2.2.1.3 Existing Resources

At the time of writing, the US Government CISA has issued a number of materials related to UAS and cybersecurity. These include a January 2023 document entitled "Secure Your Drone: Privacy and Data Protection Guidance," which provides high-level information on basic UAS security and privacy protection best practices.

Disaster responders who use UAS should be required to review this document prior to deployment in the field. This document should also be incorporated into standard training provided to disaster responders who anticipate flying UAS themselves or working with UAS data.

The CISA "Secure your Drone" document is not specifically oriented toward disaster response. Resources should be dedicated to developing specialized recommendations and best practices for UAS cybersecurity in the specific context of disaster response. These resources should be paired with those developed to minimize the risk of UAS data privacy violations, as described in Section 2.5 of this document.

2.3 Requirements for a Central Database of UAS Capabilities

What are the requirements for a central database of UAS system and sensor capabilities, taking into consideration airworthiness and encryption factors? These capabilities should be based on standard test methods. Platforms should be vetted by real-world practitioners in the disaster and emergency response domain. An agency should be identified to host and maintain this database.

The UAS market is constantly changing, and there is considerable need for a standardized, well-researched database of UAS system and sensor capabilities.

2.3.1.1 UAS Capability Database: Key Considerations

Central considerations for such a database should include:

Compliance. Aircraft used in disaster response must adhere to US regulations pertinent to unmanned aircraft, including Part 89 Remote ID. Disaster response operations may entail flight over people: aircraft used for these purposes should follow Part 107 Operations Over People regulations. The UAS System and Sensor Capability Database should be subject, when applicable, to the general requirements outlined for a Centralized Interagency Data Portal Database in Section 2.1 of this document.

Comprehensiveness. New UAS platforms, sensors, and software are constantly introduced to the US market. The database should be regularly updated by qualified experts, preferably on at least a bi-annual basis. The platform database could also be cross-referenced with database records pertinent to UAS accidents and incidents, enabling regulators to monitor the rate at which certain UAS products fail, break, crash, or otherwise perform in unwanted ways.

Credibility. Expert evaluators of UAS platforms, sensors, and software should be chosen carefully. They should have considerable technical knowledge of UAS platforms. They should also be familiar with disaster response operations and data collection during disaster response and should be able to evaluate how UAS technology might perform under challenging conditions.

Relevance. Although recent standards for deeming UAS equipment to be safe - such as the US Department of Defense Blue UAS program – are valuable tools, they have not (to date) been designed to meet the specific needs of emergency and disaster response operations. Disaster and emergency responders engaged in UAS data collection often require high-precision GPS capabilities, high-quality sensors, and other specific equipment that may not be present on UAS platforms that have not been developed with mapping and high-quality data collection in mind.

The database must ensure that all UAS are carefully evaluated for their capability as mapping and data-collection platforms, permitting potential users to make better-informed decisions.

Usability. The database should be easy to use, with an approachable user interface and search controls. The database should include information about UAS and accompanying tools from the vendor, photographs, and notes compiled by expert assessors.

2.3.1.2 UAS Capability Database Requirements

In addition, the following requirements must be met:

Reviewer Selection Requirements

[ASSURE-SENSOR-DB-] Reviewers should have demonstrable prior, practical experience with using UAS and UAS data in disaster and emergency scenarios.

[ASSURE-SENSOR-DB-] Reviewers should be drawn from as diverse a range of organizations and organization types as possible, such as academia, government (at all levels), law enforcement, private sector organizations, search and rescue, non-governmental organizations, and other relevant actors.

General Review Requirements

[ASSURE-SENSOR-DB-] Platform reviewers should consider the NIST/ASTM International Standard Test Methods for Response Robots.

[ASSURE-SENSOR-DB-] Platform reviewers should consider airworthiness criteria as defined by the FAA, drawing from existing Certification for Advanced Operations UAS criteria.

Hardware Review Requirements

[ASSURE-SENSOR-DB-] System resilience to rain and moisture.

[ASSURE-SENSOR-DB-] System ability to operate in windy conditions.

[ASSURE-SENSOR-DB-] System ability to operate in very high and very low temperatures.

[ASSURE-SENSOR-DB-] Amount of space/runway envelope required to safely launch and land system.

[ASSURE-SENSOR-DB-] Aircraft capability to detect and avoid obstacles.

[ASSURE-SENSOR-DB-] Aircraft compliance with Part 107 Operations Over People.

[ASSURE-SENSOR-DB-] Aircraft compliance with Part 89 Remote ID regulations.

[ASSURE-SENSOR-DB-] System's ability to capture both oblique and nadir imagery.

[ASSURE-SENSOR-DB-] RTK and/or PPK data collection capability. High-accuracy RTK or PPK systems are vital for many post-disaster mapping and pre-disaster risk evaluation tasks.

[ASSURE-SENSOR-DB-] Aircraft maximum battery life under normal conditions, as well as maximum battery life with relevant compatible payloads (such as commonly-used sensors).

[ASSURE-SENSOR-DB-] System ability to accommodate multiple sensors/sensor types.

[ASSURE-SENSOR-DB-] Number and type of sensors compatible with UAS.

Cost Review Requirements

The cost of purchasing and maintaining UAS systems is a crucial concern for disaster responders, who often operate under considerable budget constraints. These criteria should ensure that a balance is struck between operational safety and security, and ensuring that UAS systems can realistically be purchased and maintained by disaster response organizations.

[ASSURE-SENSOR-DB-] Cost and availability of maintenance for system and accessories.

[ASSURE-SENSOR-DB-] Cost and availability of replacement parts for system and accessories.

[ASSURE-SENSOR-DB-] Cost and availability of software licenses or subscriptions required to conduct UAS mapping operations.

Software Review Requirements

[ASSURE-SENSOR-DB-] Integration with commonly-used flight planning software.

[ASSURE-SENSOR-DB-] Integration with commonly-used data processing software.

[ASSURE-SENSOR-DB-] Evaluation of cloud versus offline software processing and storage solutions, taking into account case-by-case cybersecurity and network access requirement needs.

[ASSURE-SENSOR-DB-] Reliance on proprietary systems and software. Evaluate if the platform allows users to freely offload and store data. Critically evaluate if the platform pushes users towards a single software tool for functions including flight planning, data offloading, data analysis, and data storage. Platforms that "lock" data or otherwise make it challenging for users to easily access collected data should not be favored.

Sensor Review Requirements

[ASSURE-SENSOR-DB-] Sensor general type (electro-optical, multispectral, video, hyperspectral, infrared).

[ASSURE-SENSOR-DB-] Sensor manufacturer/model.

[ASSURE-SENSOR-DB-] Sensor zoom capability.

[ASSURE-SENSOR-DB-] Sensor resolution (when available/applicable).

[ASSURE-SENSOR-DB-] Sensor compatibility with other UAS platforms (i.e., can the sensor only be used with one UAS platform, or can it be used with multiple platforms)?

Security Review Requirements

[ASSURE-SENSOR-DB-] Security profile of manufacturer systems. How is the manufacturer storing data? What are their security practices? What information are they ingesting from software linked to the UAS platform? Are they open to independent security review?

[ASSURE-SENSOR-DB-] System on-board data encryption ability.

[ASSURE-SENSOR-DB-] Presence of system "kill switch" capability if system fails or crashes.

2.3.1.3 Further Considerations

A review of government agency capabilities must be carried out to determine which would be best suited to host the UAS platform database. As part of the database development process, feedback from US drone disaster response practitioners should be collected. This feedback should be focused on which UAS platform attributes are most relevant to disaster responders operating environments and circumstances. This information can then be used to develop well-informed criteria for evaluating UAS platforms for their suitability for disaster response operations.

2.4 Metrics for the Use of UAS During Disaster and Emergencies

What metrics should be created for the use of UAS during disasters and emergencies? Examples include: Acquisition, maintenance, and operation costs, Percentage of UAS in aircraft fleet, number of UAS operations (by type of disaster), number of vehicle failures per platform during disaster response operations, number of operational failures per platform during disaster response operations, effective time of UAS operations (from planning to data delivery), frequency/tempo of UAS operations in an impacted area, and number and density of UAS operations in an impacted area, etc.

Currently, little data exists on how UAS are being used in practice during real-world disasters and emergencies. In the United States, there is limited publicly available information related to how often UAS used in public safety and disaster response experience technical challenges, fail, crash, or otherwise encounter unexpected operational difficulties.

The creation of a standardized set of metrics for collecting this data should be a key priority for the federal government in the near future. This information will prove vitally important for helping UAS users, manufacturers, and regulators address problems and facilitate the wider adoption of UAS for disaster response.

Data collected using these metrics should be stored in a centralized research database, in accordance with (when applicable) database requirements outlined above. This information should be made publicly available to the extent that is possible, while still ensuring that both public and disaster response personnel security is not compromised.

Some of this data may be challenging to collect due to the inherent nature of mass disaster responses. The overall emphasis should be on filling in as many gaps as possible, while acknowledging that at present, collecting data covering all the metrics defined below may not be realistic. Efforts should be made after the acute disaster response phase is over to fill in informational gaps.

2.4.1 UAS Systems

Many of the requirements outlined here regarding UAS systems overlap with the requirements outlined in Section 2.3.

Specific details regarding UAS software and hardware could be filled in automatically for disaster events in the database by pulling in previously recorded information from the UAS Sensor and Capability Database, described in Section 2.3.

- Type of UAS (multirotor, fixed wing, etc.).
- UAS manufacturer.
- Name and type of sensors carried by UAS.
- Acquisition cost of UAS platform.
- Maintenance costs (including annual and lifetime).
- Operation costs.

- Percentage of UAS in overall aircraft fleet maintained by a given organization.
- Age of UAS.
- Hours flown by each UAS during its operational lifespan.
- Amount of time in which each UAS is undergoing repairs.

2.4.2 Organizational Information

This category covers information pertinent to organizations deploying UAS during disasters. This information could be used to compile a "roster" of known organizations that have used UAS in disaster response contexts.

- Name of organization.
- Type of organization.
- Organization location or base of operations.
- Contact information for organization, when available. Organizations should be asked for consent to share this information with the database.
- FAA Part 107 waivers held by organization.
- Certificates of Waiver or Authorization held by organization.
- Number of Part-107 holding UAS pilots within each organization.
- Number of pilot hours per pilot.
- Additional UAS and disaster response-related training, certifications, or other education received by each pilot.
- Location of UAS program within organization. UAS programs that deploy to disasters may occupy very different internal locations from organizations to organization: capturing these structural differences is valuable.
- Name and date of prior disaster incidents which organization has responded to with UAS technology, if available.

2.4.3 Individual Disaster/Emergency Incident Information

Database entries should be created for all given disaster responses over a certain size in which UAS were used.

- Name of disaster/incident.
- Brief description of disaster/incident.
- Type of disaster/incident (selected from menu).
- Number of SGI Waivers issued during disaster/incident, when applicable.
- Location of emergency/incident. This information should be stored in KML/KMZ or shapefile format, permitting the data to be readily visualized in GIS software or on a web map.
- Name of requester of UAS disaster response services during a given disaster, when applicable.
- Reason why UAS disaster response services were requested.
- Type of UAS missions carried out during disaster: categories could include search and rescue, initial video survey of impacted area, post-disaster mapping, pre-disaster risk assessment mapping, disaster rebuilding, and so forth.
- Name of organization conducting UAS operations during a given incident (for linkage to detailed organization information described above).

- Frequency/tempo of all UAS operations in impacted area/incident.
- Number and density of all UAS operations in impacted area/incident.
- Effective time of UAS operations from start to finish during a given incident (may be difficult to collect).

2.4.4 UAS Operation Software

- Name of UAS software used for flight planning.
- Name of UAS software used for data processing.
- Acquisition and operation costs of UAS software required for flight planning, data collection, and data processing.

2.4.5 Accidents/Incidents

UAS users during disasters and emergencies should be strongly encouraged to submit information about any accidents and incidents that they encounter during aerial operations to the centralized data collection portal. This will create a valuable forensic record of actual UAS performance during real-world, high-pressure disaster situations and incidents. Such information will help disaster responders anticipate potential challenges with given platforms before they occur and will provide both regulators and manufacturers with valuable safety information.

- Number of UAS failures (including crashes, losses, and serious malfunctions) per platform during disaster response operations. Detailed incident reports, including location, weather conditions, disaster details, certain operator information, and more relevant details should be appended to each incident (keeping in mind PII and security concerns for broader/public sharing).
- Number and type of other technical challenges/problems encountered during disaster response operations (that do not rise to the level of UAS failure but produce notable impediments to operations). UAS users during disasters should be encouraged to voluntarily share this information, in such a way that their identity and safety are protected.
- Number, type, and description of incidents involving interactions with the public. These might include cases where members of the public attempted to impede drone operations or attempted to harm UAS operators or equipment (such as by shooting at UAS).

2.4.6 Data Metrics

Data collection is the primary objective of many UAS flights during disasters and collecting information about these efforts will provide valuable insight for analysts and practitioners. Organizations and individuals may be able to provide researchers with valuable insight into how they handle, analyze, and store data. The anticipated Centralized Interagency Data Portal (described above) will facilitate the collection of this data-specific information.

- Overall quantity of data pertinent to a given disaster stored in the anticipated Centralized Interagency Data Portal (as measured by data size, and/or number of photos/videos).
- Type of data collected during UAS operation, such as video, photographs, infrared imagery, multispectral imagery, and so forth.
- Size of data.
- Software used to process data, if applicable.
- Was data evaluated for privacy/PII risks using a standardized procedure? (Yes/No).

- Was data redacted for privacy/PII risks using a standardized procedure, if this was deemed appropriate? (Yes/No).
- Brief description of the process used for evaluating/redacting data for PII, when applicable.
- Method of data storage.
- Anticipated length of time that data will be stored/maintained.

2.4.7 Overall UAS Disaster Response Landscape

Data from all individual disasters with a UAS disaster response component collected in the database should be aggregated to produce these overall metrics:

- Number of overall accidents/incidents.
- Percentage by type of disasters/incidents to which UAS responded.
- Frequency of UAS response to disaster by geographic area (enabling analysts to determine if UAS are more likely to be involved in disaster response in certain areas of the country).
- Overall number of disasters to which UAS responded – including annual, monthly, and bi-annual figures.
- Number of UAS operating organizations responding to disasters in a given year.
- Overall frequency of use of certain UAS platforms by type and manufacturer.

2.5 Evaluating Drone Data for Potentially Harmful Information

How can we better understand how drone data collected during disasters can be used to cause harm? What would best practices and tools for evaluating data for potential PII and security risks look like?

The widespread adoption of UAS technology over the last decade across many professional industries has been accompanied by a considerable amount of concern over the privacy and safety risks that this novel form of data collection presents to the public. These concerns about UAS have been consistently expressed in recent public opinion studies – worries that have been intensified by growing public awareness of the spread of facial recognition and artificial intelligence technologies. Members of the public also express apprehension over the prospect of government-collected UAS data being stored and used for other, unexpected and unwanted purposes.

A recent court case in Michigan presents an example of this dynamic. After township authorities flew a UAS over his property seeking information related to a zoning dispute, the landowner contended that the flight violated his constitutional rights. While the Michigan Supreme Court ruled in favor of local government in May 2024, it is likely that similar cases will be litigated in the near future, as municipalities continue to turn to UAS for a wide range of data-collection tasks.

Despite long-standing public concern over the risks presented by UAS imagery, there is still no specific federal legislation in the United States that addresses how UAS data may be collected, analyzed, or stored. In the absence of such legislation, organizations in the US and internationally have developed voluntary best practices for UAS data collection, including best practices developed by FEMA, the National Telecommunications and Information Administration's 2016 "Voluntary Best Practices for UAS Privacy, Transparency, and Accountability," the International Committee of the Red Cross's 2020 "Handbook on Data Protection in Humanitarian Information," and CISA's 2023 " Secure Your Drone: Privacy and Data Protection Guidance."

While these standards are very useful reference materials, most are relatively general documents that do not provide highly specific guidance for disaster responders tasked with evaluating and redacting UAS-collected data for potential privacy risks.

Gaps also exist in the scientific understanding of the actual risk that UAS-collected data presents to the public. At the time of writing, little scientific research work exists that attempts to quantify or clearly define how UAS collected data can lead to harm for both individuals and demographic groups. Some risks appear to be obvious: for example, high-resolution UAS imagery of a devastated flood area or airplane crash may contain images of deceased persons, information that must be treated with great sensitivity and care.

Other risks are less obvious, but no less concerning. In recent years, researchers have examined risks to the public from the dissemination of both PII and Demographically Identifiable Information (DII) – which can take many forms, from social media posts to UAS imagery. Of particular concern is the "mosaic effect," a term describing describes how different sources of data – such as UAS data collected during disaster - can be correlated to produce privacy violations by de-identifying both individuals and groups, in a way that would not be possible with just one source alone.

UAS-collected data, like different forms of aerial imagery, can be combined with other data sources – such as social media posts, fitness tracker information, cellular records, and more – to identify individuals and their patterns of movement, habits, and other sensitive information. A bad actor might be able to review high-resolution data collected from multiple UAS flights over the same location to identify a vehicle's license plate and monitor its movements – information that could be particularly dangerous in the hands of an individual with access to government data systems. Bad actors also might be able to review UAS collected data of disasters to target unattended homes for theft or could appropriate UAS imagery of identifiable deceased or injured persons, which could then be shared on social media or used to coerce family members.

The mosaic effect creates an unfortunate dynamic. As organizations and governments increase data collection efforts during disasters for beneficial purposes, so too increases the risk of this data being used in unexpected and potentially dangerous ways by other actors. While abiding by good data security and cybersecurity practices reduces these risks, it by no means removes them entirely. Data breaches, leaks, and hacks now occur frequently, exposing data to unexpected viewers. Ultimately, the only truly secure data is data that has not been collected in the first place.

Although all data collection is coupled with risk, this does not mean that data should never be collected. UAS data collection during disasters is a highly valuable practice, as has been demonstrated many times in recent history. The practice of sharing UAS data with others during disaster response operations has also repeatedly demonstrated its value – enabling many actors to take advantage of essential aerial insights. Therefore, it is in our best interests to find ways to better *balance* these risks, ensuring that UAS data collection operations can take place as safely and responsibly as possible.

Currently, there are no standardized or widely available best practices or standards for evaluating UAS data for the presence of personally identifiable information, in advance of storing the data for long-term use or in advance of sharing the data with other actors, or with the public. There are also no standardized best practices or standards for redacting, masking, or otherwise altering data to remove areas of PII risk. In the current absence of both specific regulatory guidance and scientific research into relative privacy risks, UAS users during disasters must adopt a cautious, security-minded approach to the collection, storage, and dissemination of the data that they collect.

The below requirements outline a proposed approach to reviewing drone-collected data for personally identifiable and sensitive information. The drafters of this report suggest that these requirements be expanded upon by a team of subject matter experts, providing disaster responders with a clear set of best practices for evaluating drone-collected information for these sources of risk.

These best practices must be introduced and implemented in conjunction with the Interagency Data Portal outline in Section 2.1. Aggregating large amounts of UAS data collected during disasters into a single, centralized location will inevitably create a significant degree of privacy risk to the public (as is the case for any centralized database). It is crucial that best practices surrounding evaluating UAS data for sensitive information and PII are developed and deployed to reduce that risk.

Once developed, these best practices could then be used to inform the creation of software to assist analysts in reviewing large UAS data sets collected during disasters. This software could include tools capable of using artificial intelligence to automatically flag potentially problematic images for further review by human analysts. Such tools could expedite the review process, balancing the need to protect the public from privacy risks against the equally compelling need to collect and share UAS data as quickly as possible during disasters.

2.5.1.1 General

[ASSURE-PII-RISK-1] The set of best practices must be published as a publicly available document.

[ASSURE-PII-RISK-2] The set of best practices must be accompanied by a training module or curriculum.

[ASSURE-PII-RISK-3] The set of best practices must balance two key priorities: detecting PII and sensitive information to ensure the public is not put at risk, as well as the need to share data as quickly as possible during disasters and emergencies.

[ASSURE-PII-RISK-4] The set of best practices must emphasize that all UAS data collection during a disaster is accompanied by inherent privacy and security risks to people on the ground.

[ASSURE-PII-RISK-5] The set of best practices must emphasize the necessity of ensuring that a minimum amount of UAS data is collected to achieve a given disaster-response objective, keeping in mind the inherent privacy and security risks associated with its collection and storage.

[ASSURE-PII-RISK-6] The set of best practices must be condensed into a short-form document, accompanied by a short training module, for “just in time” training during an immediate disaster.

[ASSURE-PII-RISK-7] The set of best practices must be developed by subject matter experts on UAS data and PII and DII risks.

[ASSURE-PII-RISK-8] The set of best practices must include cyber-security informed recommendations for securely storing and controlling access to UAS collected data.

[ASSURE-PII-RISK-9] All UAS data contributors to the Centralized Interagency Data Portal described in Section 2.1 must be required to adhere to this set of best practices prior to uploading or sharing data.

[ASSURE-PII-RISK-10] Administrators of the Centralized Interagency Data Portal must perform their own review of submitted data, in alignment with the defined set of best practices, for PII and sensitive information prior to sharing it with other portal users.

[ASSURE-PII-RISK-11] The set of best practices must be reviewed by legal experts with expertise related to PII, privacy, and cybersecurity.

[ASSURE-PII-RISK-12] Trainings related to the set of best practices must emphasize the necessity of legal review to ensure that all activities are in compliance with relevant federal, state, and local law.

[ASSURE-PII-RISK-13] The set of best practices must include a clear and legally-reviewed definition of what constitutes PII and sensitive information in the context of UAS data collected during disaster.

[ASSURE-PII-RISK-14] The set of best practices must include descriptions and examples of the harmful outcomes that may result from unauthorized actors gaining access to UAS-collected PII and other sensitive information.

2.5.1.2 Technical

[ASSURE-PII-RISK-15] The set of best practices must provide clear workflows that data analysts can productively follow to quickly review UAS-collected data sets (including imagery and video) for material containing PII or other sensitive information.

[ASSURE-PII-RISK-16] The set of best practices must define clear chains of responsibility and responsibility-to-inform when it is discovered that UAS may have collected PII and other sensitive information in the course of disaster response activities.

[ASSURE-PII-RISK-17] The set of best practices must include a risk matrix, developed by specialist professionals, that UAS data collectors can use to evaluate the relative risk of collecting PII and other sensitive materials during a given UAS disaster response data collection operation.

[ASSURE-PII-RISK-18] The set of best practices must provide authorized and secure visual examples of what common forms of PII and other sensitive information might look like in UAS imagery and video captured from different altitudes. Such examples could take the form of both still images and video data.

[ASSURE-PII-RISK-19] The set of best practices must provide clear specifications for redacting or removing areas containing PII or other sensitive information using specific software tools, while emphasizing the necessity of ensuring that such activities are legally permissible in a given jurisdiction and context.

3 CONCLUSION

This research provides foundational concepts for a path forward when using UAS to collect data during a disaster or emergency situation. Data sharing and storage must be carefully considered as data is collected and used to assess damages and other needs and response efforts from coordinating agencies. This report provided insight from multiple levels of government and organizations who respond to disaster events. High-level research questions surrounding the requirements and implementation of cybersecurity efforts, central database framework, and metrics for the use of UAS are answered in this report.

Cybersecurity efforts should include protection against outside invasion and internal training efforts for geospatial users of the UAS data to adhere to confidentiality and protection against any adverse impacts of storing and sharing potentially personal identifiable information. There is a need for a central database that would include information of the UAS data collected during disasters including easy-to-use upload, search, and review tools. A crucial part of this centralized data portal would include the incorporation of security and privacy protection. Furthermore, this report concluded the need for a standardized set of metrics that would benefit UAS users, manufacturers, and regulators for UAS in disaster response.

Moving forward, further research is vital in setting up a robust centralized interagency data portal that ensures easy access to UAS operators authorized to respond to disaster events to capture and upload all relevant data needed by agencies to effectively and safely respond, while maintaining high security protocols around use and storage of this data to protect individuals.

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Appendix E. Task 9-1 Technical Research Report

The FAA's Center of Excellence for UAS Research
ASSURE
Alliance for System Safety of UAS through Research Excellence

CNA
3003 Washington Boulevard
Arlington, VA 22201

A11L.UAS.68: Disaster Preparedness and Emergency Response Phase III

Data Exchange Requirements Document for Database

September 2024

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NOTICE

LEGAL DISCLAIMER

Version History

Date	Revision	Version
3/30/2023	Initial release	1.0
9/30/2024	Update release	3.1

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CSV	Comma-Separated Value
FAA	Federal Aviation Administration
LMS	Learning Management System
NIST	National Institute of Standards and Technology
RPO	Recovery Point Objective
RTO	Recovery Time Objective
UAS	Unmanned Aircraft Systems

1 INTRODUCTION

In any public safety mission, no matter how large or small, local first responders are the first to arrive on the scene, the last to leave, and the most likely to save lives and reduce property damage. With increasing instances of severe disasters, first responders must have access to the best available technology to successfully carry out their missions. Unmanned Aircraft Systems (UAS) can significantly enhance emergency response capabilities when safely integrated into operations.

To maximize the efficacy of UAS, data gathered from flight missions must be organized and made available to analysts and decision-makers quickly and efficiently. Any unnecessary delay in this process may result in the data being outdated and useless by the time that they reach those who can use them. As such, there is a clear need for a centralized UAS flight data management hub wherein the data from individual UAS flights can be collated as part of a larger emergency event effort and made accessible to Public Safety Commanders and decision-makers in as close to real time as possible. Alliance for System Safety of UAS through Research Excellence (ASSURE) aims to meet this need with the Flight Events System.

Data captured by the data collector will be used for test events, post-event analysis, and other evaluation and analysis efforts. Data collected during the project will be analyzed to produce various key performance measures and metrics that characterize overall pilot proficiency in a test environment. The forms of data collection are:

- *Digital data collection:* Data captured from system capabilities, test activities, and various digital formats that are submitted directly to the data collector database. In addition, digital data may be collected via Excel spreadsheets, Google Docs, Application Programming Interfaces, flight logs, etc., and processed per a format specified by a data management plan and sent to the data management team after the completion of the test event.
- *Observation:* During test events, observers at each test lane will observe different tests (e.g., systems capabilities, remote pilot proficiency), record actions, take notes on critical items, administer questionnaires, and conduct debrief discussions with test participants.
- *Surveys:* Data from surveys will be used to gather qualitative data from participants regarding test operations, lessons learned, and any other pertinent information.

1.1 Document Purpose

This document provides high-level requirements for the data collector and database in support of the framework and is based on research and lessons learned from the A28 UAS Disaster Preparation and Recovery project. A28 was intended to develop safe, effective, and standardized methods to enhance disaster recovery and emergency response using UAS. Through research, interviews, and surveys, the A28 team found that the lack of a coordinated and verifiable UAS training and evaluation system was a substantial barrier to the effective deployment of UAS during disasters. There is a clear and demonstrable need for UAS data sharing, operational standards, and pilot proficiency and credentialing for first responders.

2 CAPABILITY, DESCRIPTION, AND PROGRAM INFORMATION

This document defines the high-level requirements for developing a data collector and database. The requirements outlined in this document apply to the following project tasks:

- The development of a *database* to collect UAS capabilities and pilot proficiency data. The prototype database will be used for evaluation purposes in the test environment. Data captured by the data collector will use an authorized cloud service architecture and model design.
- The development of a *data persistence architecture* in accordance with cloud services best practices. All data captured as part of the effort shall be made available according to agreements for reporting.
- The development of *data storage and backup procedures* in accordance with cloud services best practices. Archiving of operation data and test data from the partners and/or (universities). The ASSURE Team will manage test data collected for future analysis as needed.

2.1 Operational Concept

It is envisioned that development of this UAS data framework will ultimately result in a definitive sole-source for all first responder UAS pilot proficiency for different operations as well as a repository for mock emergency response flight event data for ongoing analysis. This framework is an integral part of a larger, multiagency effort to better integrate UAS into public safety operations.

2.1.1 High-Level Operational Concept

Figure 1 illustrates a notional system and data architecture for the Data Collector and Database.

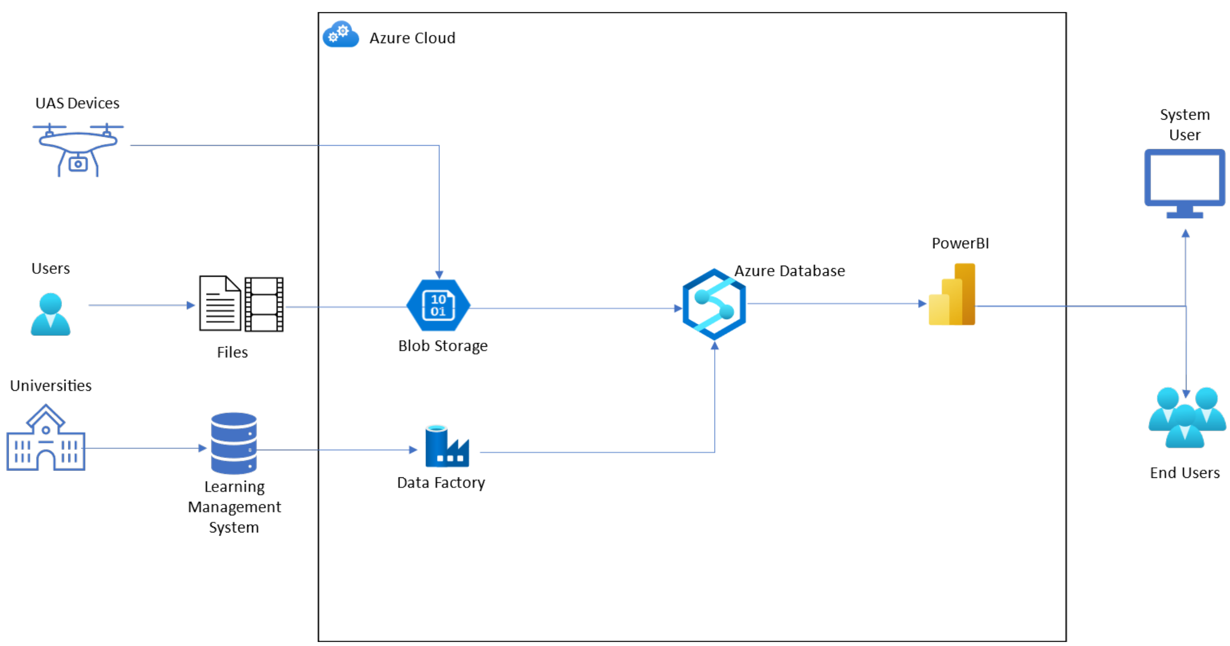

Figure 1. High-Level Data Collector and Database Workflow Architecture.

ASSURE is developing protocols and best practices for the deployment of UAS in emergency response and public safety scenarios, and testing these practices in mock events helps validate and refine them. In addition, pilot proficiency and credentialing helps to build trust in the operators both within their agencies and among the public they serve. The Data Collector and Database workflow architecture activities include, but are not limited to:

- Collecting data from public safety mission profiles and use cases such as live video feed, geospatial mapping, 3D mapping, flight event data, and pilot proficiency data.

- Storing products from collected data to include still images, video files, 3D models, and flight events data.
- Analyzing the data, reporting on the data, and sharing it using web-based tools.

2.2 Constraints

- Adequate network bandwidth.
- Firewall boundaries preventing communication between source and target databases.

3 FUNCTIONAL AND PERFORMANCE REQUIREMENTS

3.1 Functional Requirements

3.1.1 General

[ASSURE-DB-01] The data collector and database must be deployed in a cloud environment.

[ASSURE-DB-02] The data collector and database must provide industry-standard service methods to support data exchange between public safety users.

Note: Refer to the Data Management Plan and Integrated Plan for Information Sharing document

3.1.2 Database

[ASSURE-DB-03] The database must store the data collected from the pilot proficiency source system and from flight events in a cloud database.

[ASSURE-DB-04] The database must provide 99.99 percent availability.

[ASSURE-DB-05] The database must be monitored for performance degradation.

[ASSURE-DB-06] The database resource capacity must be able to scale as user demand increases.

3.1.2.1 Data Collection

[ASSURE-DB-07] The database must store files recorded.

[ASSURE-DB-08] The database must store data points in accordance with the National Institute of Standards and Technology (NIST) Standard Test Methods for Small Unmanned Aircraft Systems.

[ASSURE-DB-09] The database must store results from pilot proficiency assessments as provided by the relevant systems.

[ASSURE-DB-10] The database must store the data from surveys that will be used to gather qualitative data from participants regarding test operations, lessons learned, and any other pertinent information.

3.1.2.2 Data Persistence

[ASSURE-DB-11] All data stored in the cloud must remain available unless otherwise requested to be archived or removed.

3.1.2.3 Data Storage and Backup

[ASSURE-DB-12] Daily database backups must be taken and kept for a minimum of 7 days.

[ASSURE-DB-13] The Recovery Point Objective (RPO) must be within 1 hour.

[ASSURE-DB-14] The Recovery Time Objective (RTO) must be within 12 hours.

[ASSURE-DB-15] Backups must be monitored for failures to ensure the RTO and RPO targets.

3.1.2.4 Users

[ASSURE-DB-16] Database users who require elevated privileges to perform administrative-level duties must be authorized administrators.

[ASSURE-DB-17] Database users who need to run reports must be restricted to read/write permissions.

[ASSURE-DB-18] Database users must adhere to the principle of least privilege best practices.

[ASSURE-DB-19] Database user passwords must be at least eight characters long.

[ASSURE-DB-20] The password must contain characters from three of the following four categories: English uppercase letters, English lowercase letters, numbers (0-9), and non-alphanumeric characters (!, $, #, %, etc.).

3.1.2.5 Data Management

[ASSURE-DB-21] Survey data sourced from the source pilot proficiency database(s) must be replicated to the cloud.

[ASSURE-DB-22] Structured data must be in CSV and Parquet file formats for compatibility with the cloud object storage.

[ASSURE-DB-23] Metadata from flight test events must be stored in the cloud.

[ASSURE-DB-24] The data in object storage must be kept unless otherwise requested by the customer.

[ASSURE-DB-25] Data must be made available through a cloud reporting service.

[ASSURE-DB-26] Direct access to the data must not be made available to end users.

[ASSURE-DB-27] Personal Identifiable Information must not be stored.

[ASSURE-DB-28] Data storage devices must be redundant and able to tolerate failures.

3.1.3 Data Visualization and Reporting

[ASSURE-DB-29] The presentation layer must be delivered through a cloud reporting service.

3.2 Data and Information Requirements

3.2.1 Data Governance

Data governance fosters a common vision of data-related practices and promotes more effective use of data. It improves understanding of the data collected, reported, and used by program areas and the organization. As a result, the policy promotes more consistent, efficient, and coordinated responses to data issues and enhances communication and collaboration among program, technology, and other staff.

Note: The data management team will mostly be comprised of ASSURE team members and will be further defined in future documents.

[ASSURE-DB-30] The data management team must determine which users must have access to the systems that pertain to their areas.

[ASSURE-DB-31] The data management team must determine who is granted access to which data and at what granularity within the system.

[ASSURE-DB-32] Requests for access to data must be reviewed by the data management team in coordination with the customer.

[ASSURE-DB-33] Any changes to data collection must be reviewed by the data management team to determine the impact and level of effort.

[ASSURE-DB-34] Data must be released through cloud reporting services.

3.3 Performance Requirements

3.3.1 Database Performance

[ASSURE-DB-35] Performance must be monitored for the cloud database reports.

3.3.2 Data collector Performance

[ASSURE-DB-36] The data collector processes must provide near real-time data transfer performance.

4 SECURITY REQUIREMENTS

4.1 Database Compliance Standards

The database must comply with the following security standards: International Organization for Standardization 27001, System and Organization Controls 2, Federal Risk and Authorization Management Program, NIST 800-53, and Cloud Security Alliance Security, Trust, Assurance, and Risk. These standards will ensure that the database is designed, implemented, and maintained with security as the primary consideration, providing robust protection for the confidentiality, integrity, and availability of data.

4.2 Information System Security Requirements

[ASSURE-DB-37] Data must be kept confidential and made available to only authorized parties.

[ASSURE-DB-38] Data integrity must be preserved and not tampered with after submission.

[ASSURE-DB-39] The database must be made available to users with resiliency against various types of failures.

5 QUALITY AND CONFIGURATION MANAGEMENT REQUIREMENTS

5.1 Quality Assurance

[ASSURE-DB-40] The database MUST comply with FAA-STD-016A, Quality Control System Requirements.

5.2 Configuration Management

[ASSURE-DB-41] Versions of the schema and the changes to the objects must be tracked.

[ASSURE-DB-42] Changes to data collection must also be documented, and a formal review process must be established.

6 TEST AND EVALUATION REQUIREMENTS

6.1 Development Testing

[ASSURE-DB-43] The database must comply with developmental acceptance tests to demonstrate the successful creation of a cloud database.

[ASSURE-DB-44] The database must comply with developmental acceptance tests to demonstrate a successful creation of a schema within the cloud database.

[ASSURE-DB-45] The database must comply with developmental acceptance tests to demonstrate a successful connection to external pilot proficiency and assessment database(s).

[ASSURE-DB-46] The database must comply with developmental acceptance tests to demonstrate a successful copying data from external pilot proficiency and assessment database(s) to the cloud.

[ASSURE-DB-47] The database must comply with developmental acceptance tests to demonstrate a successful importing data from object storage file sources into the cloud database.

[ASSURE-DB-48] The database must comply with developmental acceptance tests to demonstrate a successful importing data from UAS flight event data input portals to the cloud.

6.2 Operation Testing

[ASSURE-DB-49] The database must comply with operational acceptance tests to demonstrate all functional, data, and performance requirements are satisfied.

Appendix A References

Federal Aviation Administration. (2024). Data Management Plan for Flight Events (Version 1.1). Washington, DC: FAA.

Federal Aviation Administration. (2024). Integrated Plan for Sharing Agreements (Version 1.1). Washington, DC: FAA.

Federal Aviation Administration. (1987). Quality Control System Requirements (FAA-STD-016A). Washington, DC: FAA.

Microsoft. (2023). Azure subscription and service limits, quotas, and constraints. https://learn.microsoft.com/en-us/azure/azure-resource-manager/management/azure-subscription-service-limits#data-factory-limits.

Microsoft. (2023). Azure SQL. https://learn.microsoft.com/en-us/azure/azure-sql/managed-instance/resource-limits?view=azuresql

National Institute of Standards and Technology. (2022). Standard Test Methods for Small Unmanned Aircraft Systems. (ASTM). Gaithersburg, MD: NIST.

Appendix F. Task 9-2 Technical Research Report

3003 Washington Boulevard
Arlington, VA 22201

A11L.UAS.68: Disaster Preparedness and Emergency Response Phase III

Database Design and Architecture

September 2024

v 1.1

NOTICE

LEGAL DISCLAIMER

Version History

Date	Revision	Version
3/30/2023	Initial release	1.0
9/30/2024	Update release	3.1

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TABLE OF ACRONYMS

ASSURE	The Alliance for System Safety of UAS through Research Excellence
CPU	Central Processing Unit
FAA	Federal Aviation Administration
LMS	Learning Management System
MSU	Mississippi State University
RDBMS	Relational Database Management System
SSO	Single Sign-On
UAS	Unmanned Aircraft System
UVM	University of Vermont
VM	Virtual Machine

1 INTRODUCTION

In any public safety mission, no matter how large or small, local first responders are the first to arrive on the scene, the last to leave, and the most likely to save lives and reduce property damage. With increasing instances of severe disasters, first responders must have access to the best available technology to successfully carry out their missions. Unmanned Aircraft Systems (UAS) can significantly enhance emergency response capabilities when safely integrated into operations.

To maximize the efficacy of UAS, data gathered from flight missions must be organized and made available to analysts and decision-makers quickly and efficiently. Any unnecessary delay in this process may result in the data being outdated and useless by the time that they reach those who can use them. As such, there is a clear need for a centralized UAS flight data management hub wherein the data from individual UAS flights can be collated as part of a larger emergency event effort and made accessible to Public Safety Commanders and decision-makers in as close to real time as possible. Alliance for System Safety of UAS through Research Excellence (ASSURE) aims to meet this need with the Flight Events System.

Data captured by the data collector will be used for test events, post-event analysis, and other evaluation and analysis efforts. Data collected during the project will be analyzed to produce various key performance measures and metrics that characterize overall pilot proficiency in a test environment. The forms of data collection are:

- *Digital data collection:* Data captured from system capabilities, test activities, and various digital formats that are submitted directly to the data collector database. In addition, digital data may be collected via Excel spreadsheets, Google Docs, Application Programming Interfaces, flight logs, etc., and processed per a format specified by a data management plan and sent to the data management team after the completion of the test event.
- *Observation:* During test events, observers at each test lane will observe different tests (e.g., systems capabilities, remote pilot proficiency), record actions, take notes on critical items, administer questionnaires, and conduct debrief discussions with test participants.
- *Surveys:* Data from surveys will be used to gather qualitative data from participants regarding test operations, lessons learned, and any other pertinent information.

1.1 Document Purpose

This document describes the database architecture for the Disaster Preparedness and Emergency Response Program. Tasks will include the data governance, data management, and system architecture needed to develop the data collector and database.

The purpose of this design is to provide a storage and analysis framework for UAS flight test event scenarios and to extract certain data elements from the pilot proficiency and assessment database and store them in a centralized location in the cloud for credentialing purposes.

1.2 High-Level Operational Concept

Figure 1. High-Level Data Collector and Database Workflow Architecture illustrates a high-level system and data architecture for the data collector and database.

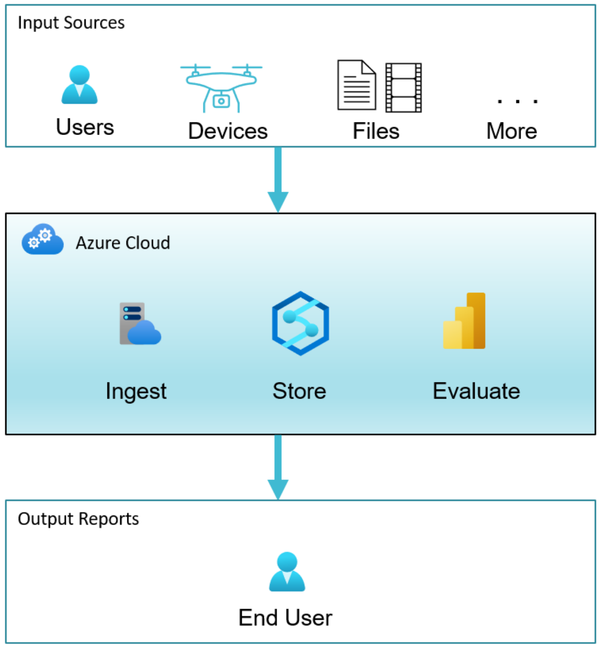

Figure 1. High-Level Data Collector and Database Workflow Architecture.

The database will support data storage and analysis of mock emergency response scenarios, including drone and mission data, designed to test proposed emergency response procedures. The database will also support a testing and evaluation system that assesses and certifies first responder UAS pilot proficiencies. The data collector and database workflow architecture activities include:

- Collecting data from public safety mission profiles and use cases such as live video feed, geospatial mapping, 3D mapping, flight event data, and pilot proficiency data.
- Storing products from collected data to include still images, video files, 3D models, and flight events data.
- Analyzing the data, reporting on the data, and sharing it using web-based tools.

2 ASSUMPTIONS, CONSTRAINTS, AND RISKS

2.1 Assumptions

- The database does not have high availability requirements that would require a database clustering solution.
- The database will comply with recovery requirements that are made available by the cloud service (i.e., Microsoft Azure).
- Procedures for capturing and storing drone and mission data will be developed for event scenarios.

2.2 Constraints

- Tracking and recording data will need to be formalized in future agreements and plans.
- Relevant system components must be compatible with Mississippi State University data infrastructure.

2.3 Risks

- The long-term operational maintenance and retention strategy is yet to be determined.

3 DATABASE DESIGN APPROACH

The database design approach is focused on data transfer automation and a cloud native structure. The cloud vendor, Microsoft Azure, was chosen because of its reputation as an industry leader and its familiarity within CNA from previous experience. SQL Server is the database engine of choice because it is the most mature Relational Database Management System (RDBMS) offering from Microsoft Azure. The other system components were selected because they are the cloud-provided services specific to the required data collection functionality.

3.1 Functional Design

This section describes how the database meets the functional requirements.

1. The database is required to be cloud based.
2. The database is required to support read and write workloads.
3. The database is required to integrate with a reporting and visualization solution.
4. The database is required to store data from multiple sources.
5. The database is required to store data in multiple formats, including structured and unstructured.
6. The database is required to control access to approved users and systems.
7. The database is required to have industry-standard security.

3.2 Database Management System

The design approach calls for a mature RDBMS that can grow and scale as users increase. The cloud provides the ability to increase storage or compute resources on demand with little service interruption. The cloud also allows flexibility for high availability should the requirements change in the future.

3.3 Security

The Azure database will offer multiple layers of security through:

- Virtual networks – Isolate data and environments within separate virtual networks, thereby reducing the effectiveness of unauthorized monitoring or interference.
- Firewall rules – Block unwanted computer traffic, preventing access to the network from malicious software.
- Restricted database access – Implement verification methods and control access permissions to known individuals/systems to reduce data breaches and threats.

4 DETAILED DATABASE DESIGN

4.1 Logical Data Model

The data structure for the pilot proficiency and assessment data has been developed in detail, allowing for ease of registration, and certification. Development of data models for pilot proficiency, drone data, mission details, proctor observations, and other sources will continue to mature as the programs are developed and tested.

The Flight Events Tool requires an additional set of data structures, detailed in Figure 2. Flight Events Data Model. These tables store details and metadata related to UAS pilots, the events they are authorized to contribute to, and metadata describing the uploaded data.

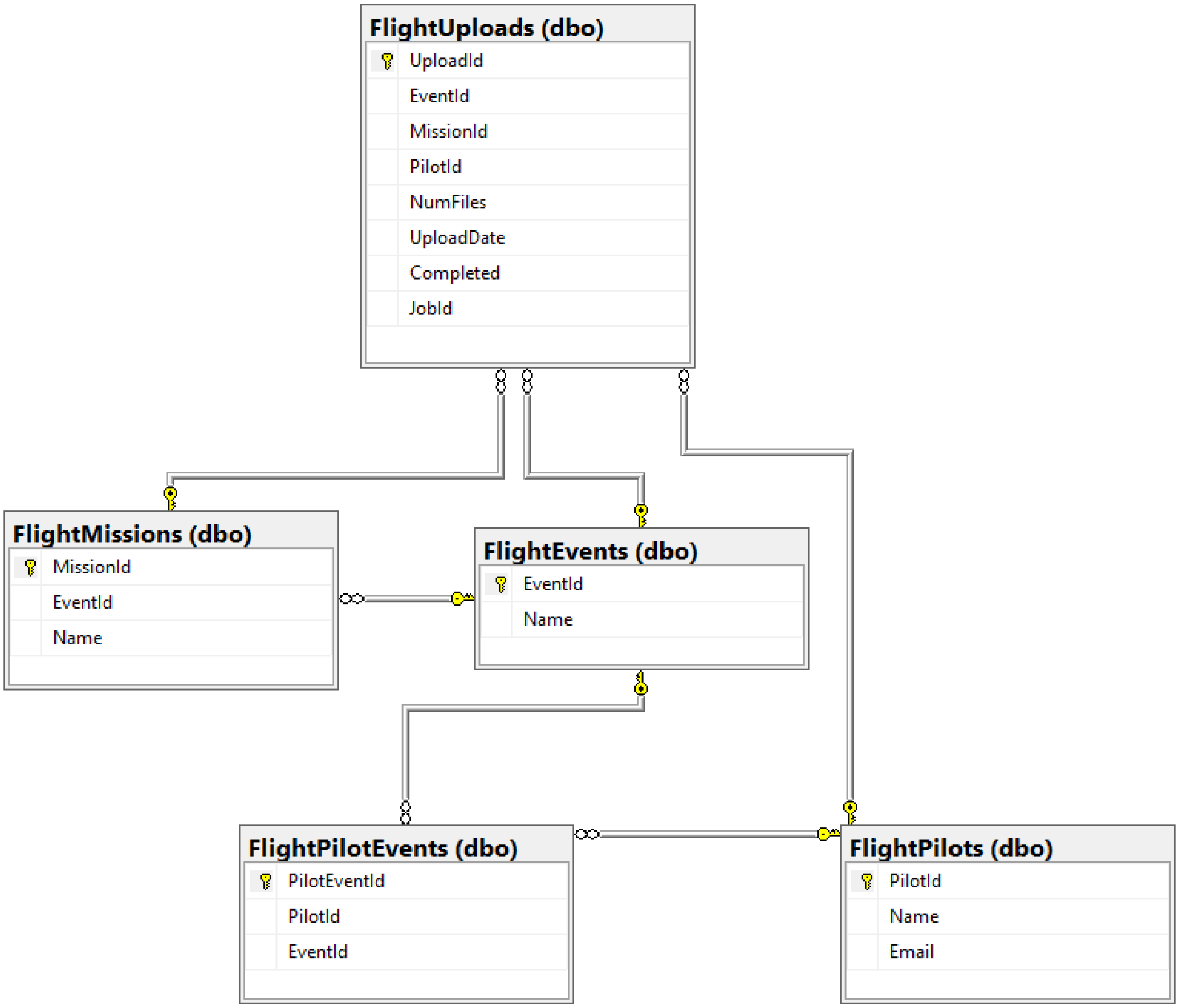

Figure 2. Flight Events Data Model.

4.2 Database Object List

Table 1. Database Object List.

Object Name	Object Type	Description
FlightEvents	Table	Describes a Flight Event which Pilots may contribute to
FlightMissions	Table	Describes Flight Missions connected to a given Flight Event
FlightPilots	Table	UAS Pilot details
FlightPilotEvents	Table	Connects a Flight Pilot record to the Flight Events the pilot is authorized to contribute to
FlightUploads	Table	Contains metadata pertaining to flight data uploads for a given Flight Mission

4.3 System and Subsystem Components

4.3.1 System Overview

The architecture described in this document is centered around a database for collecting data and storing device and mission data produced during mock or real drone applications in disaster scenarios as detailed in Figure 3. Detailed Flight Events Tool System Diagram., along with pilot proficiency and assessment data as detailed in Figure 4. High-level Pilot Proficiency Data System Diagram.

SQL Server is the central data warehouse database. This database will be fed information from different sources:

- UAS flight data uploaded via the Flight Events Tool pilot portal:
    - Metadata describing drone flight mission data uploads (e.g., what mission an upload pertains to, time and date of the upload, which pilot performed the upload).
    - Metadata captured during drone flights (e.g., metadata encoded within the images such as latitude and longitude).
- Pilot profile data uploaded via a member portal.
    - Records pertaining to credentialing searches such as city or state of work, current contact information, and consent to be included in credentialing searches.
    - Confirmation of external credentials attained by pilots (e.g., Part 107 license numbers)

See the *Data Management Plan* document for further details on data requirements pertaining to the Flight Events Tool.

The Azure Data Factory (ADF) service is used to implement the data pipeline between the Pilot Proficiency backend database and the data collector database.

Flight event data is uploaded to the system via the Flight Events Tool Pilot Portal, accessible via the web, and hosted in the Azure cloud as an Azure Web App. Uploaded data is transmitted to the Ingest Service, a Python application running within an Azure Container App, which transmits uploaded data to Blob Storage, the Data Collector database, and an ArcGIS Online app associated with the Flight Event.

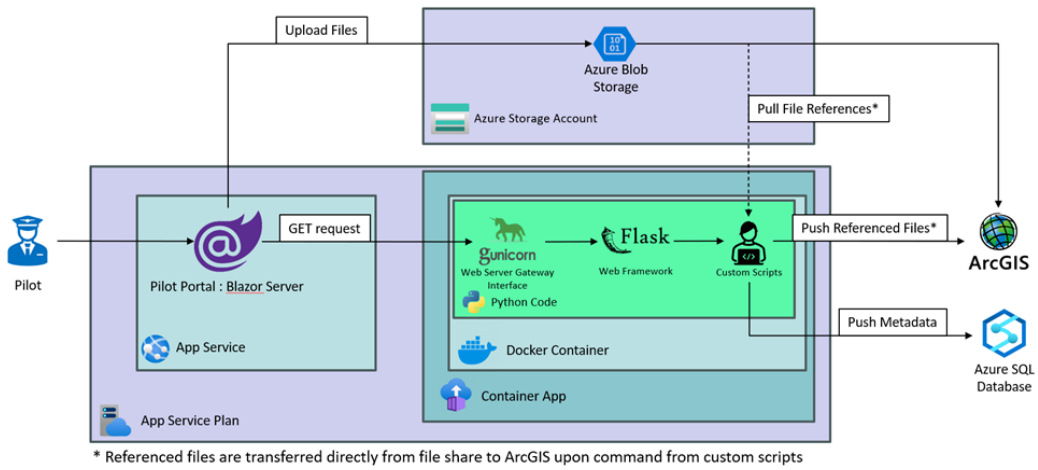

Figure 3. Detailed Flight Events Tool System Diagram.

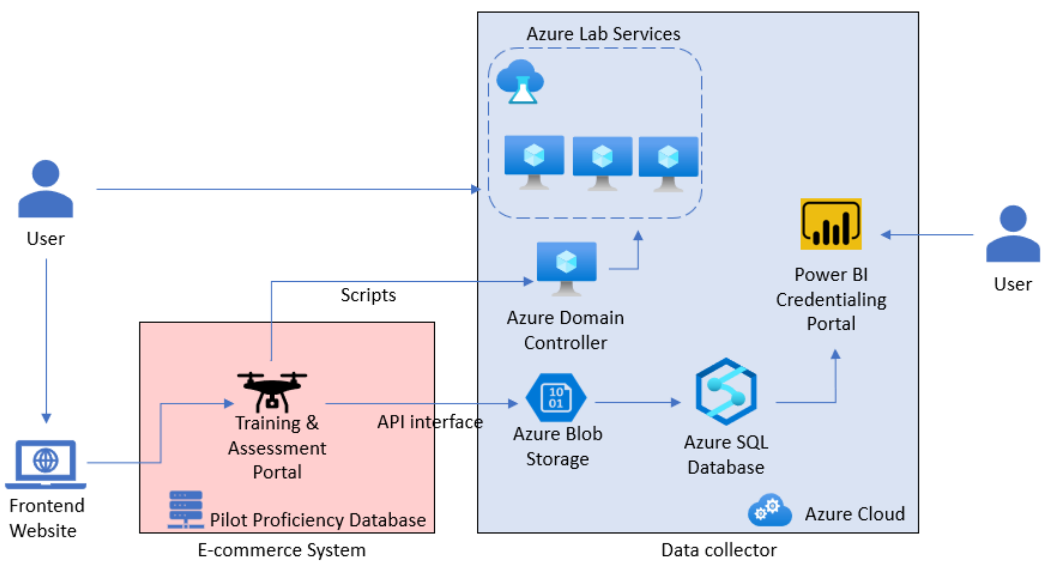

Figure 4. High-level Pilot Proficiency Data System Diagram.

4.3.2 Azure Domain Controller

- This is to maintain the domain controller for Single Sign-On (SSO).

- Active Directory is replicated across the Azure Entra ID
- Users (students, instructors, etc.) are created here as domain users and, using Azure Domain Connect, integrate with Azure Domain Controller.
- Supports scalability of the architecture, allowing the number of concurrent machines to change between needs.
- This is to maintain the SSO for software in the Azure Lab Virtual Machine (VM) for students.

4.3.3 Azure SQL Database

The Azure SQL database stores data ingested from registrations, on-site data collected in person, and drone and mission data from flight missions. This information will then be presented to verify who has authorization to fly drones in emergency response roles and to assess the feasibility of proposed missions. The methodology for loading this system will vary based on the source type.

4.3.4 Azure Data Factory

Azure Data Factory is Azure's data movement and orchestration service. It allows for the movement of data to the Data Collector database.

4.3.5 Azure Blob Storage

Azure Blob Storage is an object storage to store various types of files that aren't suited for integration with the relational SQL database but can be ingested to other systems. It will be used to provide a landing spot for documents collected in person during flight events, data collected during drone flight missions, or any other relevant activities. These documents will then be loaded into the Azure SQL Database, if applicable.

4.3.6 ESRI

The ESRI software suite, including ArcGIS Online and ArcGIS Pro, is used as a data output mechanism for the Flight Events Tool. ESRI software licenses are controlled and distributed by the University of Vermont (UVM).

4.3.7 Azure App Service

Azure App Service is a web server hosted in the Azure cloud which hosts:

- Flight Events Tool Pilot Portal web app.
- Ingest Service container app.

4.3.8 Blazor Server

Blazor Server is a web application framework on which the Pilot Portal website is built.

4.3.9 Pilot Portal

Pilot Portal is the website through which Pilots can upload data collected during UAS flight missions.

4.3.10 Azure Container App

Azure Container App is hosting service that runs the Docker container which contains the custom Python code and related web framework infrastructure to make it accessible to the Pilot Portal. A Docker container is a self-contained environment that contains all of the dependencies for the code running within it.

4.3.11 PowerBI
PowerBI is a presentation and reporting service for overall project evaluation, presentation of first responders' qualifications, and other data analysis.

4.3.12 External Devices and Tools
These devices and tools interface with the Flight Events Tool to collect data that will be stored in Blob Storage and the Azure SQL database. Examples include:

- Drone flight data.
- ArcGIS mission data.

4.3.13 Other Files
Additional files may be added to the Azure Cloud data storage. These would be sent through Blob Storage via manual uploads for processing into the Azure SQL database, if applicable. This includes on-site assessments by instructors and notes pertaining to mission data.

5 DATABASE ADMINISTRATION AND MONITORING

This section describes how the databases will be maintained and supported.

5.1 Roles and Responsibilities
The FAA will benefit from cooperation between the CNA, ASSURE, and UVM for data collection and the database capabilities for first responder pilot proficiency information and for flight event files and associated metadata. CNA is responsible for managing the Azure environment, including related databases. ASSURE is responsible for subscription ownerships. UVM is responsible for overall project management. As the project matures, the FAA will provide guidance and evaluation to evolve the capabilities enabled by the database.

5.2 Cloud System Information
Cloud System components will consist of the Azure SQL database, Azure Data Factory, Azure Data Blobs, Azure Domain Controller, Azure Lab Services, and Azure App Services. Additional components may be required and defined as the system matures. CPU, memory, and software versions will be allocated and controlled per agreements to be determined as the system matures.

5.3 Performance
Performance will be monitored and maintained through automated jobs provided through the Microsoft Azure subscription that will alert when there is high resource utilization, such as CPU, memory, and long-running queries.

5.4 Storage
Storage space for the Azure SQL database will grow automatically as needed, and therefore will not need to be monitored closely.

The Pilot Proficiency and Assessment database will be an on-premises installation on the Azure Cloud, and as such the storage space will not grow automatically. Storage will be monitored through automated jobs provided through the Microsoft Azure subscription, and additional memory will be manually allocated if necessary.

5.5 Backup and Recovery
The Azure SQL databases will be backed up using the standard backup and recovery plan provided by the Azure Cloud providers.

6 PROJECT DEVELOPMENT

6.1 Next Steps

The Disaster Preparedness and Emergency Response database and Data Collector are nominally complete; however, several infrastructure changes are in development to improve upon the system. These improvements include:

- Enhanced feature set for the Flight Events tool.
- Implementation of a system-wide SSO schema via Azure Entra ID.

Appendix A References

Federal Aviation Administration. (2024). Data Management Plan for Flight Events (Version 1.1). Washington, DC: FAA.

Federal Aviation Administration. (2024). Integrated Plan for Sharing Agreements (Version 1.1). Washington, DC: FAA.

Federal Aviation Administration. (1987). Quality Control System Requirements (FAA-STD-016A). Washington, DC: FAA.

Microsoft. (2023). Azure subscription and service limits, quotas, and constraints. https://learn.microsoft.com/en-us/azure/azure-resource-manager/management/azure-subscription-service-limits#data-factory-limits.

Microsoft. (2023). Azure SQL. https://learn.microsoft.com/en-us/azure/azure-sql/managed-instance/resource-limits?view=azuresql

National Institute of Standards and Technology. (2022). Standard Test Methods for Small Unmanned Aircraft Systems. (ASTM). Gaithersburg, MD: NIST.

Appendix G. Task 9-3 Technical Research Report

The FAA's Center of Excellence for UAS Research
ASSURE
Alliance for System Safety of UAS through Research Excellence

CNA

3003 Washington Boulevard
Arlington, VA 22201

A11L.UAS.68: Disaster Preparedness and Emergency Response Phase III

Data Management Plan For Flight Events

September 2024

v 1.1

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Version History

Date	Revision	Version
12/18/2023	Initial release	1.0
9/30/2024	Update release	3.1

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TABLE OF ACRONYMS

ASSURE	Alliance for System Safety of UAS through Research Excellence
FAA	Federal Aviation Administration
NDA	Non-Disclosure Agreement
PE	Proposed Extension: this marker refers to features that are included in the original Flight Events Tool design work, but are not implemented within the current development scope
UAS	Unmanned Aircraft System

1 INTRODUCTION

In any public safety mission, no matter how large or small, local first responders are the first to arrive on the scene, the last to leave, and the most likely to save lives and reduce property damage. With increasing instances of severe disasters, first responders must have access to the best available technology to successfully carry out their missions. Unmanned Aircraft Systems (UAS) can significantly enhance emergency response capabilities when safely integrated into operations.

To maximize the efficacy of UAS, data gathered from flight missions must be organized and made available to analysts and decision-makers quickly and efficiently. Any unnecessary delay in this process may result in the data being outdated and useless by the time that they reach those who can use them. As such, there is a clear need for a centralized UAS flight data management hub wherein the data from individual UAS flights can be collated as part of a larger emergency event effort and made accessible to Public Safety Commanders and decision-makers in as close to real time as possible. Alliance for System Safety of UAS through Research Excellence (ASSURE) aims to meet this need with the Flight Events System.

1.1 Document Purpose

This document defines how data pertaining to UAS flight missions will be handled during the development, deployment, and maintenance of the program. It will provide definitions of the different types of data that will be gathered and stored in service to the program. A set of guidelines will be established to dictate which data are to be gathered and from what sources, which data are to be shared and with whom, and how data no longer in active use are to be archived and retained.

Note: This document is subject to change as the data management needs evolve and mature.

1.2 Scope

The scope of data management includes the gathering, transformation, and stewardship of drone data collected during UAS flight missions, supplemental data required for building ArcGIS Online Apps, and personally identifiable information from UAS Operators and public safety personnel.

The UAS data in question come from test flight missions, and real emergency response scenarios.

Note: Some features and related data management requirements outlined in this document refer to proposed future development efforts on the Flight Events Tool beyond the current scope of funding. Proposed Extension (PE) work beyond the initial scope is designated throughout the document with the marker.

2 GENERAL DATA MANAGEMENT

2.1 System Overview

The Flight Events system provides a centralized management hub through which flight mission data can be collected and disseminated in support of emergency relief efforts. It establishes an automated data pipeline through which data gathered during UAS flight missions are ingested, organized, and relayed directly to analysts and decision-makers. Data from individual flight missions that support the same effort are organized as part of a larger public safety Event. Figure 1 shows a high-level overview of the flow of data within the system.

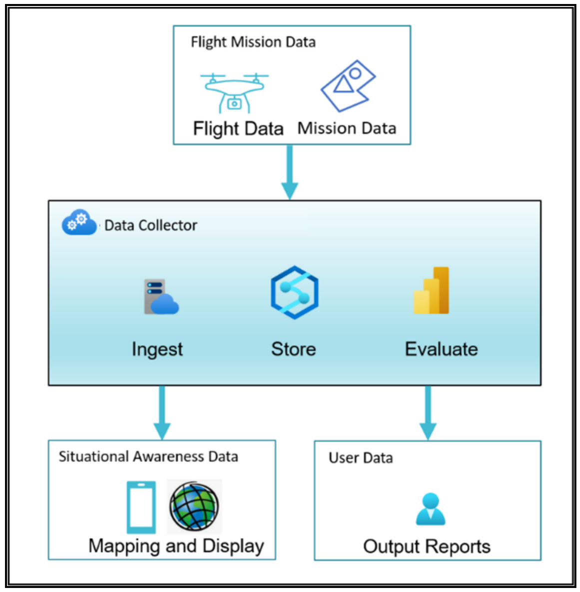

Figure 1. Flight Events System Overview

Events are the highest-level organizational units in the system. An Event represents the response effort for a real-world emergency event or disaster. For each Event, UAS Operators may upload the results—generally images and videos—gathered during UAS flight missions. These data are automatically processed and loaded into the Event's associated ArcGIS Online App.

One App is generated for each Event. An Event's App organizes and displays flight mission data on a map, with geotagged images and videos displayed at the locations where they were taken (PE). In addition to the flight mission data described above, situational awareness data include the following:

- Organizational units and their memberships, which govern with whom the data are shared.
- Styling configuration of maps, layers, and data points.
- Additional tags added to uploaded images, which are used for filtering (i.e., different flight mission data points).

In addition, these data are inserted into the Data Collector, an SQL database. From this database, PowerBI can be used to generate reports and graphics (PE).

2.2 Data Description

2.2.1 Flight Mission Data

Flight mission data include the information gathered by a UAS during a flight mission. The exact combination of data retrieved from a flight mission may vary depending on the make, model, and configuration of the UAS.

2.2.2 Image Data

Image data consists of still photos in varying formats and resolutions, depending upon the configuration of the UAS. These are photos taken during the UAS Flight Mission and make up the majority of the expected input.

See Section 2.3.1 for further details on image file format standards.

2.2.3 Video Data
Video data consists of videos in varying formats and resolutions, depending on the configuration of the UAS. These are videos taken during the UAS Flight Mission.

See Section 2.3.2 for further details on video file format standards.

2.2.4 Geospatial Data
Geospatial data refers to supplementary data that provide geospatial context to images or videos. In the case of images, these include altitude, latitude, and longitude. These data are typically included as part of the EXIF metadata tags embedded into the images themselves. Video files will contain similar data points, but in the form of a .SRT file which provides these data points at given video timecodes. These geospatial data are used to place the images or videos on the map in an ArcGIS Online App.

See Section 2.3 for further details on metadata standards.

2.2.5 Other Metadata
The EXIF metadata tags included with image and video data vary depending upon the configuration of the UAS, but generally contain information related to the camera settings and properties. These metadata may be useful for analytical purposes, as they allow for detailed comparisons of images, and will be preserved in the Data Collector database and the descriptions of data points within ArcGIS Online Apps.

2.2.6 User Data
Some personally identifiable user data are required to authorize actors within the system to perform actions. These include names, email addresses, and hashed passwords for UAS Operators, Public Safety Commanders, ArcGIS Users, PowerBI Users, and System Administrators. Additional data are required to link users to their approved Events. These data ensure that only those users who have been approved may interact with the system.

2.3 Data Format and Metadata Standards

2.3.1 Images
The expected file types for UAS images are .JPG, .PNG, and other common image file formats. A full list of acceptable image file formats will be provided as the project progresses. Images may contain a varying number of metadata fields describing the state of the UAS when the photo was taken. What metadata are available varies depending on the configuration of the UAS, so metadata must be considered an optional input. The expected metadata tags are in Appendix B.

2.3.2 Videos
Video files may be included from UAS flight missions. The expected file types for videos are common video file formats such as .MP4 or .MOV. Included with the video may be a subtitle file with additional metadata entries describing the state of the UAS when the video was taken. These files may vary, depending on the model and configuration of the UAS, but will generally be plain text files with the extension .SRT. What metadata are available are dependent upon the configuration of the UAS, so metadata must be considered an optional input. The expected metadata tags are in Appendix B: in the case of video files, these tags will be included as part of a subtitle file that maps the data to video timecodes.

2.3.3 ArcGIS Online Apps

ArcGIS Online Apps are web mapping applications hosted by ArcGIS Online. These Apps include images and their associated metadata as well as collections of ArcGIS-specific data created within the App. For long-term storage, ArcGIS Online Web Mapping Application data may be downloaded and stored in .zip format. These files may be redeployed to an ArcGIS Online App in the future.

2.3.4 SQL Table Schema

SQL tables store data related to UAS image data, user rule and permissions data, and upload metadata. The important tables are:

- **FlightEvents –** Describes flight events.
- **FlightMissions –** Describes flight missions, related to FlightEvents.
- **Flight Pilots –** Describes pilots that can be assigned to Events and Missions.
- **FlightPilotEvents –** Key table that connects a given pilot to a given FlightEvent.
- **FlightUploads –** Stores metadata related to data uploads.

See Appendix C for a detailed view of the database schema.

3 DATA COLLECTION AND ANALYSIS PROCESS

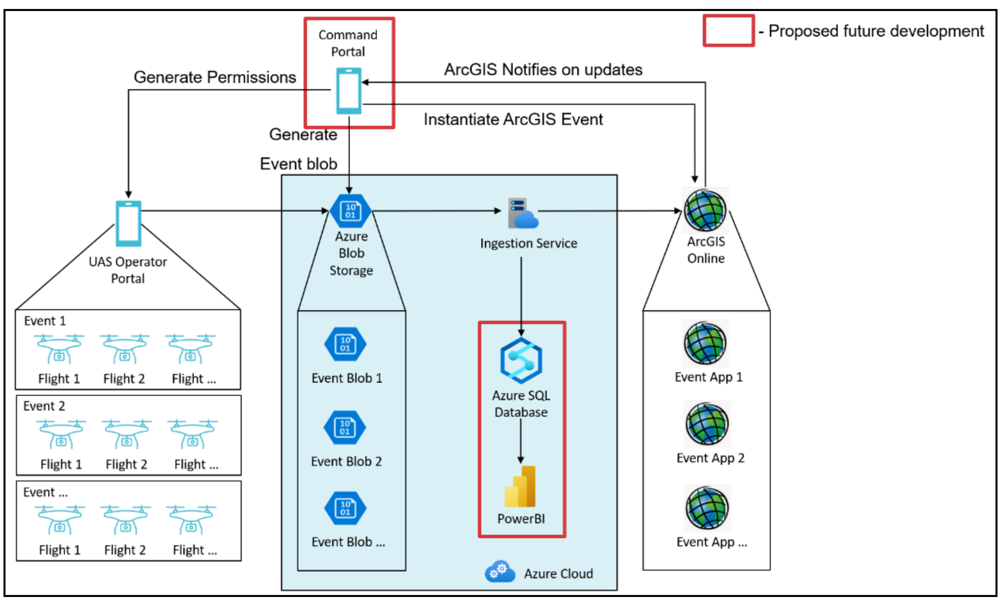

Figure 2. Flight Event System Overview

Figure 2 provides a high-level illustration of the Flight Event System. Note that components bordered in red refer to proposed future development efforts not covered within the initial A62 development scope. The following sections describe in detail the different components and processes.

3.1 UAS Operator Portal

The UAS Operator Portal is the interface through which UAS Operators can upload flight mission data to the system. Operators may choose from the Events that they are approved to contribute to and upload collections of UAS data segmented by flight mission. The uploaded data will then be pushed to the relevant Event Blob Storage, with no further action required of the Operator.

Planned future additions to the UAS Operator Portal include:

- A message center through which UAS Operators may receive directives from Public Safety Commanders.
- Functionality to support editing or undoing previous uploads.

3.2 Command Portal

Note: This is a proposed future addition to the Flight Events Tool. All the described Command Portal features in the initial release are performed by CNA engineers.

The Command Portal is the interface by which Public Safety Commanders interact with the system. Through this interface, Commanders may do the following:

- Initiate new Events.
- Archive completed Events.
- Request previously archived Events be un-archived and made active again.
- Approve or revoke access to other users.

When a Public Safety Commander creates a new Event, the necessary infrastructure to support the Event is initialized, including a unique Azure Blob Storage instance, a new ArcGIS Online App, and any required database records.

Once an Event is created, the Commander may add other users, including UAS Operators, ArcGIS Users, and other Commanders. These users are identified via email address: once added, users will receive an email, as well as a push notification if they have a relevant portal application installed, where they will provide any necessary information and set a password that they will use to access the Event. Data pertaining to user access are stored in the Azure SQL database.

At any time, Commander users may remove access to any non-Commander user, which will move the user into an Inactive Users group and notify the user via email and push notification that they no longer have access to the Event. Removing a Commander user requires intervention by an Administrator.

Once an Event is completed, a Commander may archive it, which removes all access rights to the system across the board and pushes the data into Cold Storage. These data, including any UAS data and ArcGIS Online Apps, will no longer be accessible to users and will be moved to long-term storage. Commanders may request that an Event be un-archived and made available. See Sections 3.5 and 3.6 for more details on the archival process.

3.3 Data Ingestion and Processing

When UAS data are uploaded to an Event bucket from the UAS Operator Portal, they are automatically processed and integrated into the database and relevant ArcGIS Online Apps. Figure 3 shows the Flight Event System data architecture overview. The basic process is as follows:

- UAS data are pushed to the Ingestion Service
- The Ingestion Service:

  - Pushes the data files to an Azure Blob Storage directory that is unique to the upload.
  - The metadata from the images and video are parsed and pushed to the Azure SQL database (PE).
  - Images/videos and associated tags are formatted and pushed to the associated active Event ArcGIS Online App.
- When ArcGIS Online App data are updated, notifications are pushed to Commander and ArcGIS Users (PE).

3.4 ArcGIS Online App Distribution

Note: ArcGIS Online App distribution functions are a proposed enhancement not covered by the current development scope.

When an ArcGIS User is added to an Event by a Public Safety Commander, they are notified by email and push notification and provided a form by which they may connect their existing ArcGIS Online account to the App Organization. When their access rights are removed from the App, they also receive a notification. See Section 5.1.3 for further details on ArcGIS Users.

When new data are added to the Online App—an automated process that runs in response to each new upload—ArcGIS Organization members are notified by email and push notification. The maximum frequency of notifications is configurable if users do not wish to be notified for every new data addition. Users may set cooldown periods so that they are notified a maximum of once per arbitrary time interval, mute notifications for a given period, or disable notifications entirely.

3.5 Data Storage and Backup

Data are stored within the Azure Cloud ecosystem. The two primary storage components are Mission Blobs, which are stored via Azure Blob Storage, and SQL data, stored in an Azure SQL database. Active Mission Blobs are in Hot Storage, meaning they are quickly accessible but more expensive to access. Once an Event is archived, the associated Mission Blobs are moved to Cold Storage, a cheaper long-term storage solution.

To ensure availability and reliability in disaster scenarios, data are stored redundantly via Azure's Zone-Redundant Storage model. In this model, data are replicated across multiple data centers and Azure availability zones, ensuring that the system can function if service is disrupted in one or more Azure data centers while keeping storage costs reasonable.

Regular automated backups of the Azure Blob Storage containers and SQL database ensure that data are retrievable if they are lost or compromised. A reasonable number of backups will be kept to balance accessibility to older data with the cost of storage.

Deactivated ArcGIS Online Apps will be retained for future analytical purposes or for cases in which they may need to be reactivated when an Event is unarchived. When archived, the Web Mapping Application will be downloaded from ArcGIS Online and stored in Azure Blob Cold Storage. That downloaded copy of the Web Mapping Application may be redeployed to ArcGIS Online when the Event is unarchived or when that map is otherwise requested to be made accessible for analytical purposes. This archival process prevents unnecessary expenditure on Apps that are not in active use.

3.6 Data Persistence and Analysis

Once the immediate operational purpose of an Event has ended, the data are moved into Cold Storage. Blob Storage data will remain in Cold Storage indefinitely and will be accessible by Administrator Users upon request. ArcGIS Web Mapping Application data will also be included in a Blob Storage container, which may also be redeployed to ArcGIS Online for analysis purposes upon request. SQL data may be archived and stored separately to improve SQL performance on active datasets: this mechanism is to be determined.

Data persistence policies are subject to change as the operational needs of the system evolve.

3.7 Cold Storage

Note: Automated and Commander-initiated cold storage functions are a proposed enhancement outside of the initial development scope. Cold storage procedures in the initial release are performed by CNA engineers as needed.

When an Event is completed and closed, the data pertaining to that Event need to be preserved in a cost-efficient manner. Public Safety Commanders will have the ability to manually mark Events as completed at which point the archival process will proceed automatically. In addition, a policy to be determined later will be enforced to ensure that Events that have no activity logged for a period of time will automatically be archived.

Archived data will be pushed to a state in which they are accessible but accessing them may be slower. Blob Storage data will be pushed to Azure Cold Storage. In Cold Storage, data are slower to access, but the storage is significantly cheaper.

When an Event is archived, all access rights to the Event will be removed. Administrators and Public Safety Commanders will retain the rights to reactivate previously archived Events, at which point they will be provided an option to reassign some or all previous user roles.

4 DATA EXCHANGE OVERVIEW

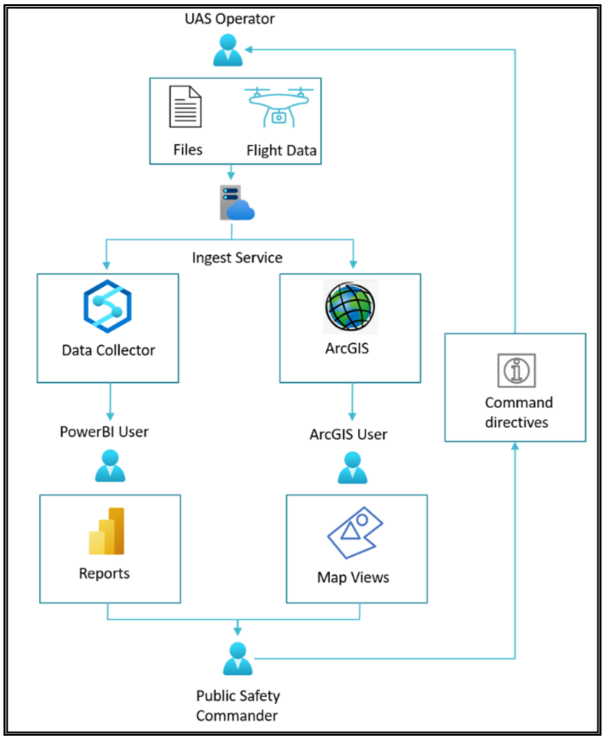

Figure 3. Data Exchange Overview

Figure 3 above describes the typical flow of data between actors in the system. The following sections detail these exchanges of data.

4.1 UAS Operator to Public Safety Commander

UAS data are added to Blob Storage and the Data Collector via the UAS Operator Portal. Python scripts pull relevant metadata from the uploaded data objects, store them in SQL tables (PE), and push them to the associated Event's ArcGIS Online App. Public Safety Commanders then access that data via the Command Portal and ArcGIS Online App.

Public Safety Commanders may issue information and directives to other users via the Command Portal. The Command Portal allows a Commander to assign users their roles and permissions as well as send directives to users via a Message Center.

4.2 ArcGIS User to Public Safety Commander

UAS Flight Mission data are aggregated within an Event's ArcGIS Online App. The App serves as the primary means of accessing that data for authorized users and is accessible via the internet. Each of these authorized users is configured as part of an ArcGIS Organization and given a role that dictates what authority they have to view or modify map data. ArcGIS Users may include Public Safety Commanders themselves or analysts and supporting staff that configure the UAS Flight Mission data into useful views that support the Event effort.

4.3 PowerBI User to Public Safety Commander

UAS Flight Mission metadata are added to the Data Collector and made accessible to PowerBI via a database connection. PowerBI users then generate reports and data visualization from the Flight Mission metadata, to be passed to Public Safety Commanders (PE).

4.4 Public Safety to Federal Aviation Administration

Output reports pertaining to ongoing or past flight events and research data are available to the Federal Aviation Administration (FAA) upon request. These data may be in the form of reports generated with PowerBI, access to ArcGIS Online App maps, or other artifacts as requested.

4.5 Data Governance

To align with the FAA's efforts to build robust, well-managed data environments, the data management framework must ensure that its Data Collector and database are designed and implemented with future growth and development in mind. Effective governance of well-defined procedures is required to ensure ongoing trustworthiness and confidence in the data because each well-managed dataset will increase the maturity, scope, and breadth of the FAA's master data.

Refer to the *Disaster Preparedness and Emergency Response Integrated Plan for Sharing Agreements* for a detailed discussion of data governance, stewardship, and infrastructure (FAA, 2023a).

5 ACCESS AND SHARING POLICIES

The flight event framework must strike a balance between ease of access for public safety personnel and data security. Too much security and it will become cumbersome to deploy during fast-paced interagency emergency response events. Too little security and data can become compromised by bad actors. As such, access roles must be defined in accordance with the principle of least privilege: all user roles will be afforded the minimum required access rights necessary to operate within the system. This practice limits the damage any individual user may intentionally or unintentionally do while still allowing good actors the ability to perform their duties unimpeded.

5.1 Access Roles and Permissions

In accordance with the principle of least privilege, user roles within the Flight Events system are defined such that each user type is given only the access rights that they need to fulfill their roles. User roles are as follows:

- System Administrators
- Public Safety Commanders
- ArcGIS Users
- UAS Operators
- PowerBI Users

5.1.1 System Administrators

System Administrators are given full access rights to the system. This group is intended to be the smallest and will consist of developers and support personnel whose roles are to configure the system and resolve technical issues.

Administrators may be further segmented into database admin, Azure admin, ArcGIS admin, and so forth as deemed necessary in accordance with the data governance and stewardship rules.

5.1.2 Public Safety Commanders

In an emergency response scenario, the primary role of a Public Safety Commander is to initiate Events and designate which users will fill the roles within that Event. These users may be other Co-Commanders, UAS Operators, or ArcGIS Users. Commanders also have read-only access to ArcGIS maps and reports to facilitate rapid decision-making.

The Commander is expected to promptly grant access to all parties necessary to carry out the effort as well as handle any "handoff" efforts in which command of the project is abdicated to another agency (i.e., a local fire department handing command off to the Federal Emergency Management Agency as a disaster unfolds).

5.1.3 ArcGIS Users

ArcGIS Users are added to an Event by a Public Safety Commander. ArcGIS Users are analysts who interpret and organize ArcGIS Online App maps to inform decision-makers. Each Event has an associated ArcGIS Online App. Each App has an associated Organization. Members of the Organization have access rights to the project determined by their role. These roles are configurable per App; however, by default, two roles are provided:

- Map Editor Users have full control over the configuration of the App, including the ability to add new feature layers and modify image tags.
- Read-Only Users may only view maps and data: they may still show or hide features and customize maps but are limited to only non-destructive edits.

ArcGIS Users are expected to analyze and interpret the flight mission data loaded into the map and configure that map such that it serves the analytical needs of the effort.

5.1.4 UAS Operators

UAS Operators are approved and allowed access to the system for a given event by Public Safety Commanders. Once approved, a UAS Operator may upload flight mission data to the system, which will automatically handle the processing of that data. UAS Operators have only upload rights: they may not view or modify any existing data in the system.

UAS Operators are expected to upload only data that are relevant to the designated Event and only data from one flight mission at a time.

5.1.5 PowerBI Users

PowerBI Users are approved and allowed access to the system for a given Event by Public Safety Commanders. Once approved, they may generate reports based on the Event data within the Azure SQL database.

PowerBI Users are expected to provide high-level meta-analysis of Event data and produce charts and reports in support of management and analytical efforts.

5.2 Removal of Authorization

When a user's operational purpose has ended in service of an Event because either the Event is closing and being archived or their services are no longer required, their authorization will be removed from the system. Prompt removal of unnecessary authorization is important in ensuring that the potential for misuse of the system is minimized. Public Safety Commanders have the authority to remove any non-Commander or non-Administrator users at any time. Removal of a Commander user will require a request to an Administrator.

When an Event is archived, all authorizations for all users are removed. If an Event needs to be unarchived, a Commander-level user must submit a request to re-enable the Event and associated permissions. See Sections 3.5 and 3.6 for further details on the archival process.

5.3 Sensitive/Secure Data Protection Policies

Some sensitive data will be required to ensure proper operation of the Flight Events system. As such, data protection procedures must be applied to guard against improper disclosure.

Personally identifiable user data are required to verify all users within the system (UAS Operators, Public Safety Commanders, etc.). These data include names and email addresses as well as some tertiary data such as business organization. Data protection best practices will be observed to ensure that no undue risk of exposure is taken upon transmission and storage of sensitive user data.

In some cases, Nondisclosure Agreements (NDAs) may apply to some of the data collected and retained. NDA policies will be made available when possible.

Given that the Flight Events system may include data that pertain to national security, it must comply with the security controls in accordance with FAA Order 1370.121B, FAA Information Security and Privacy Program and Policy.

5.4 Public Access to Emergency Management Data

Making certain data gathered from UAS flight missions public may be valuable in some cases. For example, property owners affected by a disaster event may benefit from access to images that show home damage. To account for these cases, a public access data protection plan will be developed to ensure that data may be shared with the public without risking exposure of sensitive data. Such policies will be provided in a future version of this document.

6 OPERATIONAL EVALUATION

6.1 Measures of Effectiveness

Several metrics will be used to ensure that the flight event project is meeting the goals for all stakeholders, including a mixture of usage, performance, and fault tolerance statistics. The goal is for the Flight Events system to provide positive value to all parties involved, including FAA, ASSURE, UAS Operators, Public Safety Commanders, analysts, and reporting users. A series of initial candidate statistics for measuring effectiveness are defined in the following sections, and final metrics will be established in a future version of this document.

6.1.1 Usage Statistics

Usage statistics assess how frequently users utilize the different aspects of the system and include the following:

- Number of active users.
- Number of unique Events.
- Number of flight mission datasets uploaded.
- Percentage of data types uploaded by UAS operators (images, videos, etc.).

- Number of reports generated.

These usage statistics will provide useful context as to how frequently users are utilizing the system, and what features are providing the most value to users. I.e., if users are infrequently utilizing reports, the reporting features may require re-assessing.

6.1.2 Performance Statistics

Performance statistics assess aspects such as how quickly data are processed for display and include the following:

- Time from UAS data upload to data being accessible in ArcGIS Online App.
- Report generation time.
- Loading time for UAS Operator and Commander Portals.

6.1.3 Fault Tolerance Statistics

Fault tolerance statistics assess the resilience of the system in response to errors or improper usage and include the following:

- Assessment of duplicate data and how well duplicates are removed.
- System uptime statistics.
- Frequency of bug reports, segmented by severity, and average time to resolution.

6.2 Surveys and Feedback

To ensure that the Flight Events system is responsive to user needs, a constant line of communication between users and the development team will be encouraged. Forms for users to provide feedback will be provided directly in the UAS Operator and Public Safety Commander Portals. In addition, points of contact for feedback will be provided for all users via project literature and email communiques.

To encourage direct feedback, surveys will be developed, and users will periodically be requested to complete them. Surveys may be propagated within the portals or via email, as deemed appropriate.

7 NEXT STEPS

There is no current plan or funding apparatus for the proposed enhancements to the Flight Events Tool referenced throughout this document. In the event that future development work is performed, this document may be updated to reflect new data management policies.

Appendix A References

Federal Aviation Administration (FAA). (2024). *Disaster Preparedness and Emergency Response Phase III Integrated Plan for Sharing Agreements* (Version 1.1).

Appendix B UAS Image Metadata Expected Tags

Data Name	Description	Format
Latitude	Latitude of UAS at time of photo	WGS84 coordinate
Longitude	Longitude of UAS at time of photo	WGS84 coordinate
Altitude	Altitude of UAS at time of photo	Numeric, Feet/Meters
Date taken	Date and time of photo	Datetime
Tags	Arbitrary tags that may be added by the UAS operator to provide additional context	Text
Dimensions	Dimensions in pixels of the photo	Width (px) x Height (px)
Horizontal resolution	Photo resolution along the horizontal axis	Dpi
Vertical resolution	Photo resolution along the vertical axis	Dpi
Bit depth	Number of bits used to define each pixel	Numeric
Resolution unit	Units used to define resolution	Text
Color representation	Color model used to represent colors	Text
Compressed bits per pixel	Compressed bits per pixel	Numeric
Camera maker	Make of the camera	Text
Camera model	Model name/number of the camera	Text
F-stop	F-stop setting	F-number
Exposure time	Exposure time setting	Second
ISO speed	ISO setting	ISO-number
Exposure bias	Exposure bias setting	Step
Focal length	Focal length setting	Millimeters
Max aperture	Maximum aperture setting	F-number
Metering mode	Metering mode	Numeric
Flash mode	Flash mode setting	Text
Flash energy	Energy of flash	Numeric
35mm focal length	35 mm equivalent focal length	Numeric, Millimeter
Lens maker	Make of the lens	Text
Lens model	Model number/name of the lens	Text
Flash maker	Make of the flash	Text
Camera serial number	Serial number of the camera	Text

Data Name	Description	Format
Flash model	Model number/name of the flash	Text
Contrast	Contrast mode setting	Text
Light source	Light source setting	Text
Exposure program	Exposure program setting	Text
Saturation	Saturation setting	Text
Sharpness	Sharpness setting	Text
White balance	White balance setting	Text
Photometric interpretation	Pixel composition	Text
Digital zoom	Digital zoom level	Numeric
EXIF version	Version of EXIF metadata standard	Numeric

Appendix C Database Schema

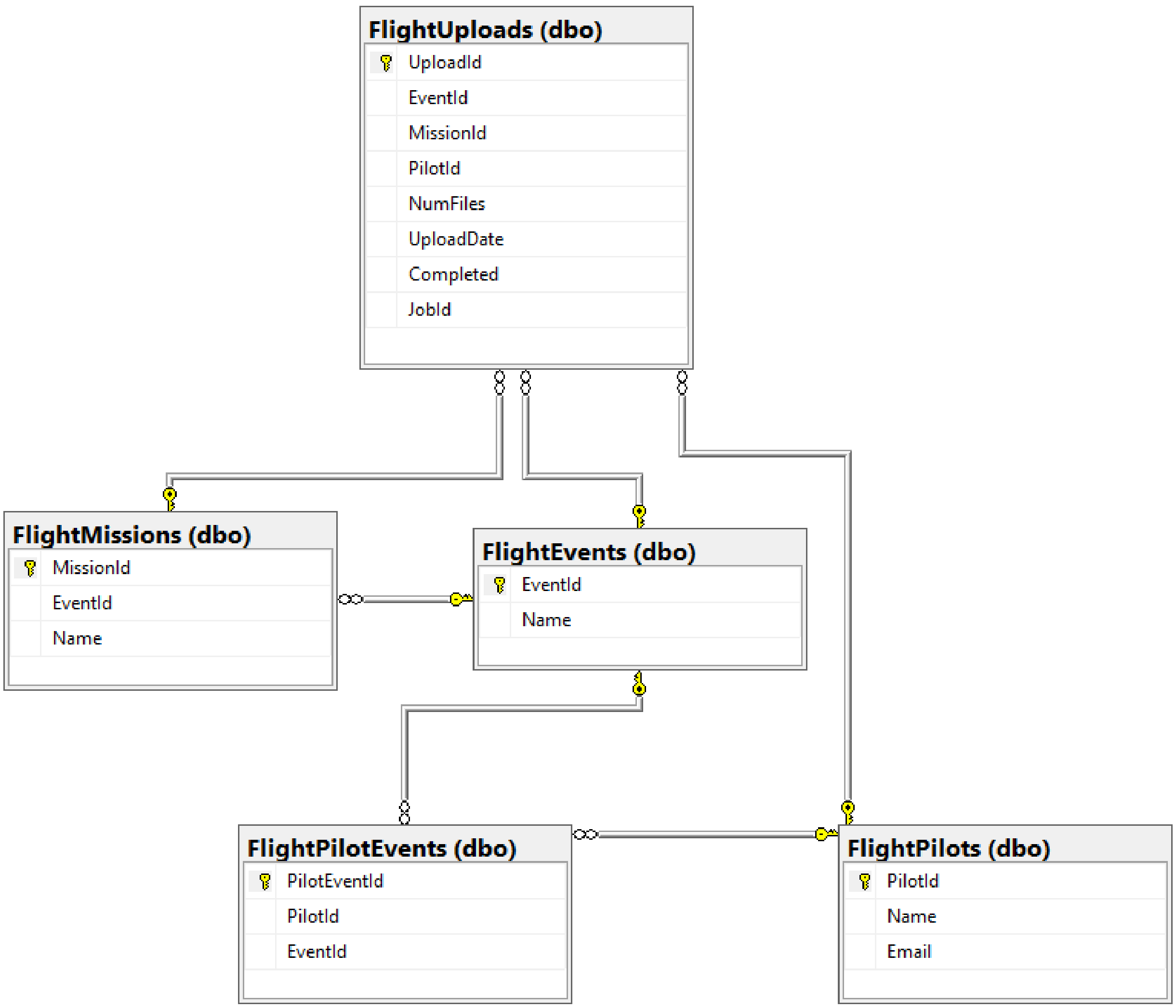

Figure 4. Flight Events Database Schema

Appendix H. Task 9-4 Technical Research Report

3003 Washington Boulevard
Arlington, VA 22201

A11L.UAS.68: Disaster Preparedness and Emergency Response Phase III

Integrated Plan for Sharing Agreements

September 2024

v 1.1

NOTICE

LEGAL DISCLAIMER

Version History

Date	Revision	Version
3/30/2023	Initial release	1.0
9/30/2024	Update release	3.1

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ASSURE	The Alliance for System Safety of UAS through Research Excellence
FAA	Federal Aviation Administration
LMS	Learning Management System
UAS	Unmanned Aircraft System

1 INTRODUCTION

In any public safety mission, no matter how large or small, local first responders are the first to arrive on the scene, the last to leave, and the most likely to save lives and reduce property damage. With increasing instances of severe disasters, first responders must have access to the best available technology to successfully carry out their missions. Unmanned Aircraft Systems (UAS) can significantly enhance emergency response capabilities when safely integrated into operations.

To maximize the efficacy of UAS, data gathered from flight missions must be organized and made available to analysts and decision-makers quickly and efficiently. Any unnecessary delay in this process may result in the data being outdated and useless by the time that they reach those who can use them. As such, there is a clear need for a centralized UAS flight data management hub wherein the data from individual UAS flights can be collated as part of a larger emergency event effort and made accessible to Public Safety Commanders and decision-makers in as close to real time as possible. Alliance for System Safety of UAS through Research Excellence (ASSURE) aims to meet this need with the Flight Events System.

Data captured by the data collector will be used for test events, post-event analysis, and other evaluation and analysis efforts. Data collected during the project will be analyzed to produce various key performance metrics that characterize overall pilot proficiency and flight operations effectiveness in a test environment.

1.1 Document Purpose

This document is intended to provide a stepping stone to the development of a fully integrated plan across all relevant stakeholders for data sharing and data management related to the Disaster Preparedness and Emergency Response project and support for the data collector and databases. Components of the integrated plan include the processes and technologies underpinning the data management system, the data management overview of the integrated plan, the data sharing operating model, and the organization and roles of the sharing entities.

Note: This document is subject to change as the data sharing needs evolve and mature.

2 PROCESSES AND TECHNOLOGY

Figure 1 illustrates a high-level system and data architecture for the data collector and database. Please refer to *Disaster Preparedness and Emergency Response Database Design and Architecture* for more details. The project's cloud environment was selected for several reasons:

- It aligns with FAA data management policies.
- It allows for easy modularity and scalability.
- It has industry-leading security features.
- It has many built-in tools supporting a variety of data input methods.
- It provides a platform for feature hosting.

Digital data is captured from system capabilities, test activities, and various digital formats that are submitted directly to the data collector database. In addition, digital data may be collected via Excel spreadsheets, Google Docs, application programming interfaces, and so forth; processed per a format specified by a data management plan; and sent to the data management team after the completion of the flight test events. These include observations during test events and surveys from participants.

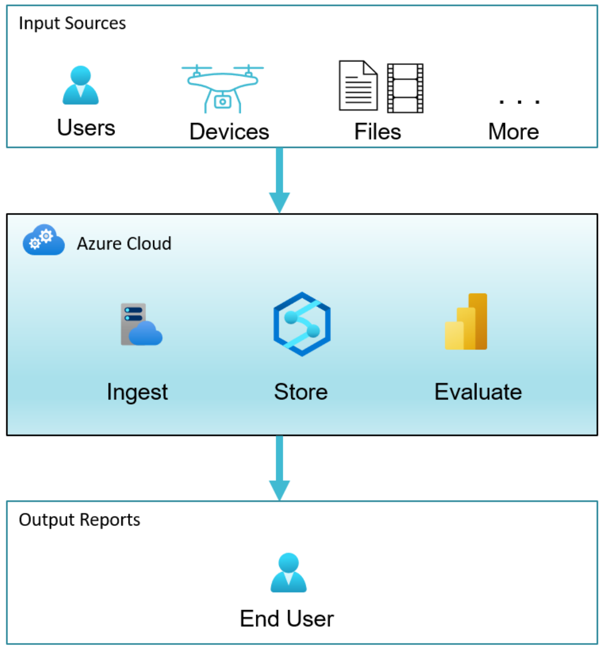


Figure 1. High-Level Data Collector and Database Workflow Architecture.

2.1 Data Security

Data security is necessary for cloud-based data management, and Disaster Preparedness and Emergency Response will follow cloud services' best practices, including data encryption at rest and in motion. In addition, data access permissions will follow role-based access control procedures.

2.2 Storage

Storage space for the Azure SQL database will grow automatically as needed, and therefore will not need to be monitored closely.

2.3 Backup and Recovery

The Azure SQL database will be backed up using the standard backup and recovery plan provided by the Azure Cloud providers.

3 DATA MANAGEMENT OVERVIEW

To align with the FAA's vision to operate in a data-centric environment, this document defines the key entities and identifies and designates managed data within the Disaster Preparedness and Emergency Response project.

3.1 Identification of Key Business Entities

Several key entities have a stake in the data and data management within the Disaster Preparedness and Emergency Response project. They are as follows:

- **FAA**: The FAA, as the project's funding agency, seeks data-driven research from the Disaster Preparedness and Emergency Response project that provides insight into the safe and secure integration of UAS into the disaster preparedness and emergency response and recovery areas.

- **ASSURE**: ASSURE, an FAA Center of Excellence and an organization largely composed of collaborating universities, such as the University of Vermont, Mississippi State University (MSU), and Kansas State University, is tasked with the overall development and management of the Disaster Preparedness and Emergency Response project, development of course material, coordination of pilot proficiency, and development of flight event plans. MSU, specifically, also manages many of the Disaster Preparedness and Emergency Response infrastructure licenses.
- **CNA**: CNA is responsible for the development of the system architecture and data management framework for the Disaster Preparedness and Emergency Response project, including the data warehouse; integration with pilot proficiency and certification data; ingestion of flight event data; and analytics capabilities.
- **Public safety entities/agencies**: Federal agencies, such as the Department of the Interior and Department of Homeland Security (including the Federal Emergency Management Agency), as well as regional, state, and local organizations, collaborate to ensure proper coordination during emergency response scenarios, using and sharing data with the Disaster Preparedness and Emergency Response project.

The Disaster Preparedness and Emergency Response project must be developed to meet the needs of each of the FAA and public safety stakeholders while also setting clear data management protocols for each entity.

3.2 Data Management Procedures

Effective data management requires procedures for the identification and submission of candidate data to the system. The data governance team is responsible for setting procedures and ensuring compliance of the data. For a data source to qualify, the source must align with the operating model outlined in Section 4: Operating Model and show how it accomplished the following:

- Eliminates duplicate or redundant data
- Delivers accurate data for downstream systems
- Monitors the integrity of the source systems
- Provides a foundation for improving data quality
- Automates otherwise resource-intensive tasks

In addition, the following information will need to be provided as applicable.

- Up-to-date logical data model
- Standardized reference data
- Defined maintenance process
- Defined stewardship roles

3.3 Designation of Data

The datasets associated with Disaster Preparedness and Emergency Response are as follows. Datasets may be added or modified in the future as requirements continue to evolve.

- **Course registration**: These data come from the pilot proficiency registration portal and include student, instructor, and course information.
- **Student certification**: These data come from the program's Learning Management System (LMS) and include course completion, grading, and certification information.
- **Surveys**: These data come from the LMS and are collected on-site at flight test events and include student, event participant, and instructor feedback.
- **UAS data**: These data come from direct file uploads or via data scraping of Simple Storage Service buckets of flight events, whether from mock or real scenarios, and include geospatial, image, and video data.
- **Data analyses**: These data are either produced within the data warehouse infrastructure or uploaded directly to the system and include course analytics and synthesized flight event data. Access to these analyses depends on the entity's requirements and can include interfaces such as PowerBI and ArcGIS Online.
- **Loose files and logs**: Additional files will exist within the data warehouse related to system information and other project-relevant data.

4 OPERATING MODEL

The operating model for data management provides structure for the evaluation, approval, and tracking of FAA data assets. The operating model is broken down into four parts:

1. Scope
2. Implementation Framework
3. Metrics
4. Governance

4.1 Scope

The Disaster Preparedness and Emergency Response data arise from two main project requirements:

- Emergency response UAS pilot proficiency and certification
- Mock and real UAS flight events used for research and coordination

The scope of these data is subject to change as these two project requirements evolve and grow, be that by the expansion of course catalogs, expansion of proficiency, or greater utilization of flight event consolidation and reporting. Activities outside the scope of these two initiatives have not yet been approved for the Disaster Preparedness and Emergency Response data management framework.

4.2 Implementation Framework

The Disaster Preparedness and Emergency Response data collector and database is implemented as a consolidation framework, as seen in Figure 2. Consolidation is a data warehouse–styled approach in which the data are copied from source systems into an operational repository. Consolidation can be implemented without needing to update source systems, but then the source systems do not gain any of the benefits of the master data. This is particularly beneficial in the case of flight events, where encouraging adoption of the system would be easier for users if it does not impact the source UAS data input into Disaster Preparedness and Emergency Response. The processes associated with mastering data will not happen in the source system but instead will occur in the operational repository.

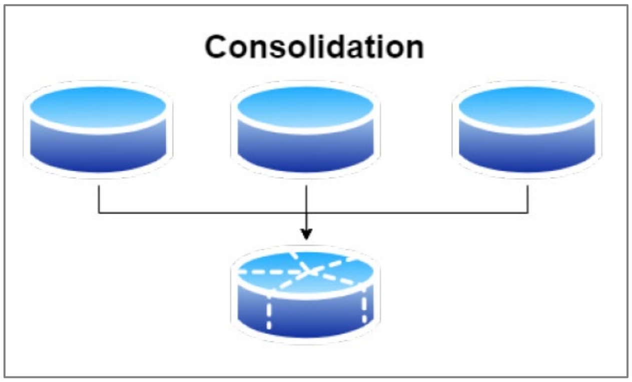


Figure 2. Disaster Preparedness and Emergency Response Consolidation Implementation Framework.

4.3 Metrics

Metrics will be used to determine whether the data succeeds in achieving the project's goals. For the Disaster Preparedness and Emergency Response project, the goals are to increase and assess pilot proficiency and to provide a centralized source of public safety and emergency response UAS flight data analyses. The measures for success include the following:

- Pilot proficiency data
- Flight event rates
- Flight event reports produced

In addition to determining the data's success for the project's goals, metrics for the data itself can be measured to ensure quality assurance. These include:

- Error rates
- Discrepancies between data source and repository
- Missing or incomplete data
- System health and security metrics
- Redundant data
- Junk data

4.4 Governance

To align with the FAA's efforts to build robust, well-managed data environments, the Disaster Preparedness and Emergency Response data management framework must ensure that its data collector and database are designed and implemented with future growth and development in mind. Effective governance of well-defined procedures is required to ensure ongoing trustworthiness and confidence in the data because each well-managed dataset will increase the maturity, scope, and breadth of the FAA's master data.

The data governance team must develop processes for the following eventualities:

- Adding new source data to the database
- Integrating new reference systems
- Monitoring the quality of the data

- Maintaining the information architecture
- Managing reference data

5 ORGANIZATION AND ROLES

A successful data management program requires a matrixed organizational structure that enables businesses and technical professionals to work in concert to properly manage data. Typically, there are three groups of people involved in data management: the Governance team, the Stewardship team, and the Infrastructure team, as portrayed in Figure 3.

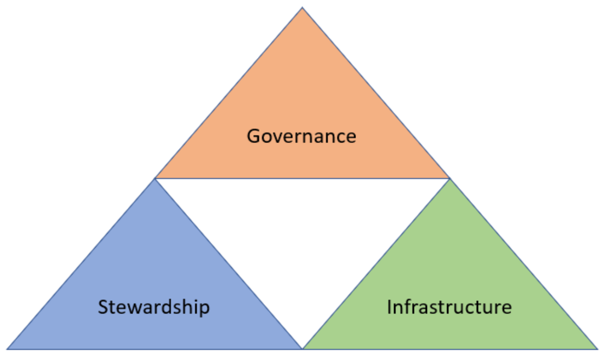


Figure 3. Data Management Organization.

5.1 Governance Team

The governance team is responsible for setting and enforcing policies around the creation, storage, use, archive, and deletion of the master data. The governance team is the decision-maker for questions regarding what ought to be done with the master data. As such, governance of project data should involve representatives with both a business and a technical understanding of the data.

The governance team will be led by ASSURE and may consist of a chair, co-chair, data governance manager, data governance analyst, and business analyst.

5.2 Stewardship Team

The stewardship team is accountable for the production, updating, definition, and integrity of project data. The stewardship team could be the individuals who perform the actual work on the project data, or it could be the individuals responsible for ensuring that the work is done.

The stewardship team will be led by ASSURE and may consist of a data steward and data custodian.

5.3 Infrastructure Team

The infrastructure team is the technical professionals who implement and maintain the data management technology and systems. They are tasked with spearheading the work of the data management initiative.

The infrastructure team will be led by CNA and may consist of a project lead, infrastructure analyst, database administrator, and technical adviser.

5.4 Responsibility and Assignment Matrix

Defining the various roles for completing tasks or deliverables as part of data management is important. Table 1 displays the overlapping responsibilities of each key entity as they pertain to Disaster Preparedness and Emergency Response project data management.

Table 1. Disaster Preparedness and Emergency Response Assignment Matrix.

	Key Entity			
Responsibility	FAA	ASSURE	CNA	Public Safety Entities
Database management			X	
Data capture from pilot proficiency data		X	X	
Data upload from UAS flight events		X		X
Governance of output analyses and ArcGIS	X	X	X	X
System security and integrity		X	X	
Project oversight	X	X		
Database development			X	
Maintenance of data sources (course, UAS, etc.)		X		X

6 PROJECT DEVELOPMENT

6.1 Next Steps

Sharing agreements will continue to evolve as the integrated system, program, and partnership composition mature. The next steps are as follows:

- Refine roles within the governance, stewardship, and integration teams.
- Finalize the input data requirements as the system reaches initial operating conditions.
- Define stewards and stewardship requirements for specific source datasets.
- Continue to refine data persistence architecture in accordance with cloud services best practices.
- Expand data storage and backup procedures in accordance with cloud services' best practices.

Appendix A References

Federal Aviation Administration. (2024). Data Management Plan for Flight Events (Version 1.1). Washington, DC: FAA.

Federal Aviation Administration. (2024). Database Design and Architecture (Version 1.1). Washington, DC: FAA.

Federal Aviation Administration. (2023). Master Data Management Strategic Plan.

Appendix I. University of Vermont Task 7 Report

TABLE OF ACRONYMS

This section is temporary and designed to provide the compiler of this report with a list of abbreviations used in UVM's report sections, to be included with the main table of acronyms in the final report.

3D	Three-dimensional
AGL	Above Ground Level
AGOL	ArcGIS Online
AOI	Area of Interest
C2	Command and Control Link
CAD	Computer Aided Design
COA	Certificates of Waiver or Authorization
CORS	Continuously Operating Reference Stations
DEM	Digital Elevation Model
DSM	Digital Surface Model
EDT	Eastern Daylight Time
EO	Electro-optical (visible or true-color)
EOC	Emergency Operations Center
EPA	U.S. Environmental Protection Agency
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Agency
GB	Gigabytes
GIS	Geographic Information Systems
GPS	Global Position System
GRS	Geographic Response Strategy
HAZMAT	Hazardous Materials
IR	Infrared (thermal)
JPG	Joint Photographic Experts Group image file
LAANC	Low Altitude Authorization and Notification Capability
LiDAR	Light Detection and Ranging
LZ	Landing or Launch Zone
MHC	Mobile Home Community
MP4/MPEG4	Motion Picture Experts Group-4 Part 14 video file
MPV	Edward F. Knapp State Airport
MS Teams	Microsoft Teams
nDSM	Normalized Digital Surface Model
NEK	Northeast Kingdom of Vermont
NIR	Near-Infrared
NM	Nautical Miles

OOP	Operations Over People Final Rule 14 CFR Parts 11, 21, 43 and 107 [Docket No.: FAA-2018-1087; Amdt. Nos. 11-64, 21-105, 43-51, 107-8] RIN 2120-AK85
PDA	Preliminary Damage Assessment
PIC	Pilot in Command
PPK	Post-Processed Kinematic
R1 GIS	FEMA Region 1 Response Division, Planning Branch GIS Team
RAW	Image file containing unprocessed or minimally processed data from the sensor
RPIC	Remote Pilot in Command
RTK	Real-Time Kinematic
RTT 1	Federal Region 1 Regional Response Team
SAL	University of Vermont Spatial Analysis Lab
SARCOP	Search and Rescue Common Operating Platform
SEOC	State Emergency Operations Center
SFM	Structure from Motion
SGI	Special Governmental Interest Waiver
SOSC	FAA System Operations Support Center
sUAS	Small Unmanned Aircraft System
TCO	Training Course Outlines
UA	Unmanned Aircraft
UAS	Unmanned Aircraft Systems
USAR VT-TF1	Urban Search and Rescue Vermont Task Force 1
UTM	Unmanned Traffic Management
UVM	University of Vermont
VCGI	Vermont Center for Geographic Information
VLOS	Visual Line-Of-Sight
VO	Visual Observer
VOC	Volatile Organic Compound
VRS	Virtual Reference Station
VT ANR	Vermont Agency of Natural Resources
VT DEC	Vermont Department of Conservation
VT FWD	Vermont Fish & Wildlife
VTOL	Vertical Take-Off and Landing
VTrans	Vermont Agency of Transportation

UAS FLIGHT TESTING EVENTS AND SCENARIOS

The Research Task Plan for this effort included the provision that the research team would conduct mock (or real) UAS flights to illustrate the use of UAS during or after different types of disasters and emergencies. These flight events were undertaken to inform the following: the technological solutions identified enable expanded UAS disaster and emergency response and recovery operations, assess the optimal type of UAS to be used during specific disasters and emergencies, the proper coordination procedures needed at the local/state/federal levels, identification of UAS metrics, how to enhance/standardize the collection and sharing of data transmitted during these missions, and any additional findings.

The final number and types of events completed by UVM are presented below:

Date(s) of Event	Event Category	Event Type (Focus)	Location	Lead Org.
12-Jun-2024	Functional Exercise	Oil Spill Response	North Ferrisburgh, VT	Univ. of Vermont (UVM)
11-Jul-2024 to 18-Jul-2024	Real-World Event	Flood Response	Barre, VT Plainfield, VT	Univ. of Vermont (UVM)
30-Jul-2024 to 1-Aug-2024	Real-World Event	Flood/Landslide Response	St. Johnsbury, VT Lyndon, VT	Univ. of Vermont (UVM)

1.1 06/12/2024, Functional Exercise, Oil Spill Response, Conducted by the Univ. of Vermont (UVM)

This functional exercise focused on the application of UAS to respond to a mock oil spill along Lewis Creek in North Ferrisburgh, Vermont on June 12, 2024. The scenario aimed to simulate an event where an oil spill from rail traffic or a tanker truck occurred along a major roadway. The exercise required collaboration between representatives from numerous agencies including ground teams for oil boom deployment and aerial teams for UAS deployment, respectively. Vertical takeoff and landing (VTOL) and multirotor UAS were deployed for data collection by teams from the University of Vermont (UVM) and the Vermont State Hazardous Materials (HAZMAT) Response Team.

1.1.1 Objectives of the Oil Spill Functional Exercise

The functional exercise served to explore the use of UAS as an effective response tool to a local or regional oil spill scenario. The exercise established a learning environment in which participants could identify knowledge gaps in policies, procedures, guidelines, best practices and coordination. Critically assessing the utility of UAS as an oil spill response tool will further the development of effective, safe and efficient use of UAS in future disaster response scenarios.

The primary objectives of this functional exercise were:

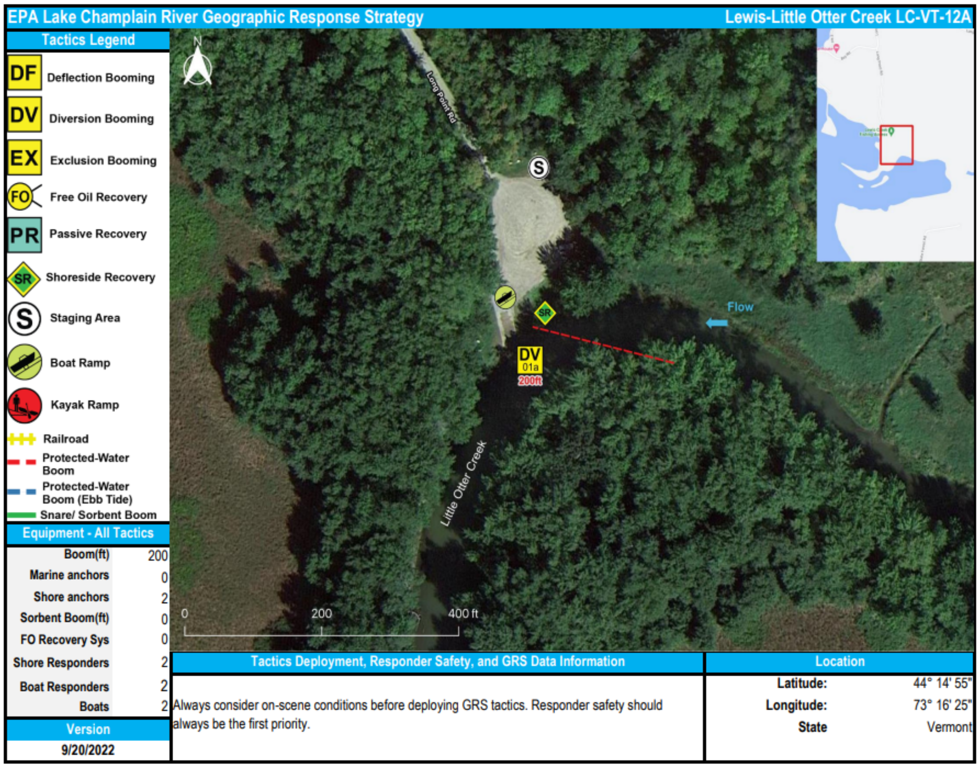
1. Establish coordination and communication between agencies necessary for an effective UAS response, including tasking, addressing communication challenges and airspace partitioning.
2. Ensure that UAS provides real-time support for emergency response efforts such as livestreaming, increased situational awareness, identifying areas of spilled hazardous materials and monitoring any resulting hazards.
3. Process and disseminate UAS imagery to enhance decision making, inspection and future planning and mitigation efforts.

1.1.2 Planning for and Logistics of the Oil Spill Functional Exercise

Planning meetings were held leading up to the functional exercise to determine objectives of the exercise, flight logistics and exercise plans, preparation tasks and other key topics. The UAS response for this mock scenario was integrated with ongoing exercises as a part of the Environmental Protection Agency's (EPA) Lake Champlain River Geographic Response Strategy (GRS). Testing of oil boom placement and simulation of shoreside oil recovery were part of GRS development and took place at specific river sites within the Lake Champlain basin.

A planning meeting was conducted virtually on April 1, 2024. Attendees included the UVM Spatial Analysis Lab (SAL) Director and UAS Team Lead, personnel from EPA Region I, Lake Champlain Sea Grant, Vermont Department of Environmental Conservation (VT DEC), Vermont Fish & Wildlife Department (VT FWD), VT HAZMAT Response Team, Absolute Spill Response LLC and Colchester Fire and Rescue. During this meeting, three GRS oil spill exercise locations and dates were introduced, with interest in UAS involvement to simulate potential response efforts. The majority of collaborators planned to focus on boom deployment, while UAS operators planned to test the feasibility of assisting ground efforts with aerial data collection. Following this meeting, the UVM UAS Team drafted a FAA Oil Spill Exercise Test Plan for the functional exercise. Once approved, this Test Plan was shared with participants and provided detailed information on the scenario and objectives, participants roles and guidance, exercise logistics, exercise scenarios, anticipated schedules, safety requirements, communications plans, and information on evaluation and post-exercise activities.

Another virtual planning meeting was held on May 3, 2024, between the UVM SAL UAS Team Lead, a UAS Specialist and the VT HAZMAT Response Team Chief. In this meeting, the location for UAS operations was selected as Lewis Creek in North Ferrisburgh, VT. Figure 1 presents the GRS at the Lewis-Little Otter Creek (LC-VT-12A) site.



EPA Lake Champlain River Geographic Response Strategy — Lewis-Little Otter Creek LC-VT-12A

Tactic #	Purpose	Response Equipment	Deployment Resources	Deployment Notes
DV-01a DV	Redirect spilled oil from one location or direction of travel to a specific site for recovery.	200 ft protected water boom marine anchor system 2 shoreline anchor system Testing Date	2 shore responders 1 response boats 1 boat operators N Tested	Deploy boom as depicted to divert incoming oil to the collection site. Anchor every 200-300'. Adjust configuration as necessary to reduce entrainment. Set up shoreside recovery. Deploy shoreside anchor first.
SR-01a SR	Remove spilled oil that has been diverted to a designated recovery site accessible from shore.	1 skimming system 1 storage tank or bladder 1 hoses, pumps, fittings N/A Testing Date	2 shore responders Tested	Set up shoreside recovery tactic at general location depicted on map.

Figure 1. EPA Lake Champlain River Geographic Oil Spill Response Strategy (GRS), courtesy of the Federal Region 1 Regional Response Team (RTT 1).

The LC-VT-12A site was selected due to the proximity of railroad tracks to a significant waterway which feeds directly into Lake Champlain. This location not only simulated an environment in which an oil spill could occur, but also incorporated elements like airspace considerations and human-based factors. The GRS at this location involved deployment of diversion booming to direct oil to a shoreside recovery site. UAS operations were planned to integrate into this ongoing exercise and supplement existing response efforts. UAS data collection types and methods were selected with the goal to enhance the overall effectiveness of a localized oil spill response. The UVM UAS Team planned to operate aerial video livestreaming and capture oblique imagery and video to provide situational awareness to on-site response personnel and/or remote emergency command facility and to inform real-time resource allocation and oil boom configuration. In addition, the UVM team would also collect multispectral imagery for mapping the extent of spilled substances in the water body. The VT HAZMAT Response Team planned to test one of their UAS platforms with onboard multi-gas and volatile organic compound (VOC) monitoring to replicate real-world UAS operations to reduce exposure to high-risk areas. A mutual goal of UAS operation was to have multiple UAS airborne in shared airspace, coordinated by flight teams.

The UVM UAS Team held an internal planning meeting on June 4, 2024. This meeting allowed the team to review the exercise Test Plan and Test Cards generated by UVM, confirm the UAS platform and sensors to be used during flight operations, and work through some of the logistics of flight plans, communication and data sharing in the field.

Another virtual planning meeting between the UVM UAS Team and VT HAZMAT Response Team was held on June 6, 2024. Exercise plan logistics were shared between teams and roles and responsibilities for UAS flight operations were confirmed.

The final meeting was held internally by the UVM UAS Team on June 11, 2024. The purpose of this meeting was to review the final exercise plan, finalize groups and individual roles and to generate a list of final tasks to complete before the functional exercise.

1.1.3 Oil Spill Response Functional Exercise Execution

The Oil Spill Functional Exercise occurred near North Ferrisburgh, VT at the Lewis Creek Fishing Access (Figure 2). The operational area was at the coordinates 44°14'55.32"N, 73°16'27.51"W, in Class G airspace. In advance of the functional exercise, the UVM UAS Team received approval for the flight operations from UVM Risk Management and the UVM UAS Working Group, who administer UAS flight operations at the University. This was facilitated through the DroneLogBook compliance management solution. As part of this approval, UAS Team staff documented relevant operational regulations, airspace classification, safety procedures, airspace monitoring, as well as other considerations. The exercise location was approximately 0.8 nautical miles (NM) northwest of the train tracks, where the simulated oil spill was set to occur. This section of Lewis Creek was downstream from the train tracks and 0.3 NM from the outlet into Lake Champlain.

Figure 2. Location of approximate flight area shown in the red polygon.

The functional exercise took place on June 12, 2024. At approximately 09:00 Eastern Daylight Time (EDT), the UVM UAS Team, the VT HAZMAT Response Team, and personnel involved in the GRS (Nuka Research, EPA Region I, VT DEC, VT FWD, Lake Champlain Basin Program, Lake Champlain Sea Grant, Republic Services, and the Shelburne Fire Department) met at the Lewis Creek Fishing Access area. Personnel from the organizations involved in the GRS that were listed above will henceforth be referred to as the "GRS Team". Once all participants arrived, a briefing was held to introduce participants and roles, discuss the general exercise plan, and cover safety information and risk management techniques. Following the briefing, the GRS Team set up their equipment near the water while the UAS teams set up within the parking area. Space was limited in the parking lot used for staging equipment, so participants stayed at the lot's edges to minimize disruptions to public use. A sign reading "UAS Flights Overhead" was posted at the entrance to the parking area and launch pads were placed away from people and obstacles with the flexibility to be moved as needed (Figure 3).

Figure 3. Staging area, including a sign notifying of UAS flights in the area (left) and aerial view of the staging area adjacent to Lewis Creek, deployed oil boom visible in the water (right).

Prior to the start of UAS operations, the UVM UAS Team and the VT HAZMAT Response Team reviewed the order of flights and deconfliction techniques to ensure safe operations within shared airspace. The order of flights was decided according to anticipated priority during a real event. The priority was livestream, followed by gas and VOC monitoring, and then mapping, with overlap between operations expected. Deconfliction and airspace partitioning techniques included utilizing hand-held radios to allow for constant communication between teams and team members, verbal communication prior to launch or land of UAS platforms, vertical airspace partitioning between UAS operations, as well as assigning additional visual observers (VOs) to monitor airspace. To allow for internet connectivity throughout operations, a Starlink wifi device and a Verizon MiFi mobile hotspot were utilized during UAS operations. Before beginning flight operations, the UVM UAS Team and VT HAZMAT Response Team conducted pre-flight safety checks using customized checklists developed by each team. The checklists were developed to encompass a variety of safety considerations and risk management protocols for any given operation. Checklists included items such as assigning Remote Pilot in Command (RPIC) and VO roles and locations, communications check, airspace and weather checks, platform and sensor checks, and review of flight plans and emergency procedures.

1.1.3.1 UAS Livestream

UVM UAS Team personnel comprised the "Livestream Team" and coordinated with the GRS Team to begin operations at a similar time. In a real-world scenario, the livestream flights could begin as soon as possible to provide a more complete view of the scene. The intention was to have a constant livestream video set up in a safe location to provide situational awareness before moving on to more complex flight operations. A DJI Matrice 350 Real-Time Kinematic (RTK) equipped with a Zenmuse H20T camera was utilized for livestream operations due to its ability to hover and manually maneuver, as well as the integration of a video streaming application with the controller. The DJI Zenmuse H20T sensor allowed for powerful zoom capability and both Electro-optical (EO) and Infrared (IR) imagery and video. The RPIC began the livestream before taking off to conserve battery life during set-up and ensure everything was functioning properly. The livestream was started by connecting the UAS controller to wifi, opening the pre-installed Microsoft Teams app, navigating to the Microsoft Teams meeting that was set-up ahead of time, joining the call, sharing the controller screen, and then navigating back to the flight application. The livestream showed the entire view of the controller, including the camera and first-person view, flight mode, battery percentage and other on-screen indicators (Figure 4).

Figure 4. DJI Matrice 350 RTK controller view during livestream flight operation and Microsoft Teams screen sharing.

The Microsoft Teams meeting was created ahead of time so that a link could be accessible and available for anyone to join the call and view the livestream. To test the livestream access, another team member used a smartphone to join the Microsoft Teams meeting via the access link and confirmed that the livestream was clearly visible. After completing pre-flight checks and setting up the livestream feed, the Livestream Team announced the commencement of flight operations and confirmed area clearance prior to takeoff at 09:35 EDT.

The UAS platform was manually flown above the staging area and then navigated across the creek at a height between 80-120 meters above ground level (AGL). The vantage point above the creek allowed for a clear view of oil boom deployment while remaining within visual line of sight

(VLOS). The altitude, viewpoint and zoom were adjusted throughout operations to provide the most useful coverage while remaining clear of other UAS operations.

Figure 5. Launch of M350 towards livestreaming location over the creek.

Throughout the exercise, the aerial livestream was not viewed or utilized for situational awareness by the GRS Team in the field, as was originally anticipated. Livestream operations can be available for review afterwards. It would be beneficial to begin recording at the start of operations when possible. Future oil spill responses would benefit from further testing and integration of livestream utility into overall operations. The livestream UAS stayed in the air during the entirety of the exercise for a total of 76 minutes of flight time, only landing twice when battery was critically low. In these cases, the UAS was manually flown back to the landing area, batteries were "hot swapped" to keep the UAS powered on, and then the UAS was launched and returned to its vantage point. During periods when the platform was not at the aerial vantage point, the controller screen was still shared through the livestream. It was recognized that the pauses in aerial coverage to swap batteries would lead to a gap in the aerial view and situational awareness. A potential future solution could be having a backup UAS positioned and livestreaming during these gaps, resulting in uninterrupted coverage for the entire exercise.

Figure 6. View of the Microsoft Teams livestream from an end user who has joined the call.

1.1.3.2 UAS HAZMAT Applications

The VT HAZMAT Response Team conducted real-time UAS gas monitoring during this exercise. Once the livestream UAS was in location, the VT HAZMAT Response Team finalized their preparation for UAS flight operations. A DJI Matrice 350 RTK was utilized for gas monitoring operations due to its payload weight capacity, ability to hover and capability to manually maneuver to features of interest. The platform was outfitted with two payloads, as well as custom 3D-printed legs. A Zenmuse H20T camera was mounted to provide image and video feed and a Honeywell Multi RAE portable 5 gas sensor was attached to the custom legs (Figure 7). Figure 8 shows the airborne UAS equipped with both sensors. The gas monitoring device was able to detect levels of oxygen, hydrogen sulfide, carbon dioxide, carbon monoxide, and volatile organic compounds. The multi-gas device was not originally intended as a UAS payload and was instead retrofitted onto the platform. In addition to attaching sensors to the platform and the team's standard pre-flight checks, the center of gravity for the UAS had to be calibrated before flight due to the unique sensor configuration.

Figure 7. Installation of gas sensor on UAS.

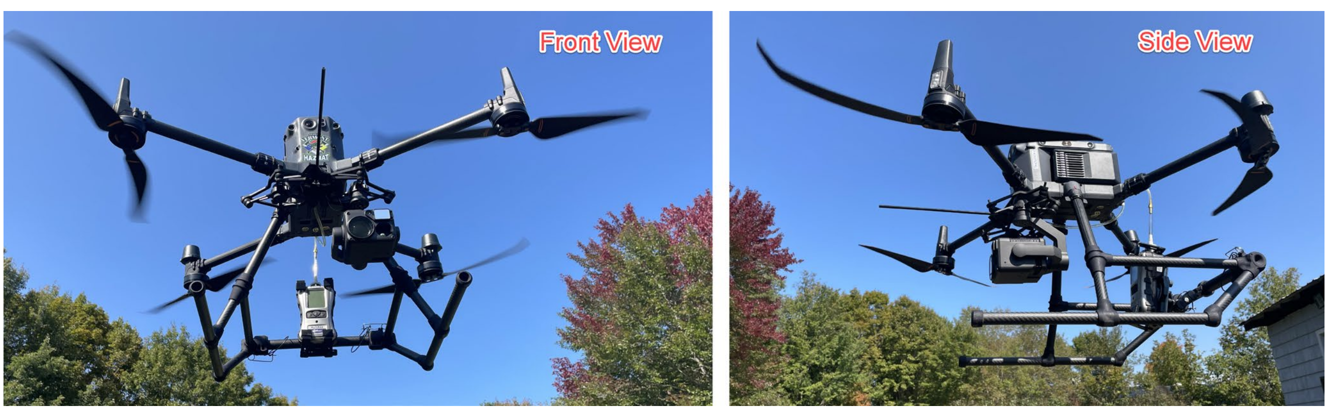


Figure 8. DJI Matrice 350 RTK platform with DJI Zenmuse H20T and retrofitted Honeywell Multi RAE gas sensor.

Flight operations were manually piloted, as the UAS needed to maneuver to different areas of interest at a low altitude to collect gas readings. Due to the way that the Honeywell Multi RAE sensor was attached to the platform, there was no way for the RPIC to directly receive readings from the gas sensor. To read the gas sensor, the VT HAZMAT Response Team devised a workaround that involved positioning the camera payload so that it could view the gas sensor screen. This method allowed the RPIC to view the gas sensor screen during flight on the UAS controller screen. VT HAZMAT Response Team members reviewed the readings as the RPIC operated the UAS (Figure 9). Viewing the gas sensor in this way greatly increased operational efficiency, as the UAS could be flown to multiple areas of interest before landing to change batteries. Without an established way to view the gas sensor, the UAS would have needed to land, and the gas sensor readings viewed on the device after flying over each area of interest (AOI). When the UAS required new batteries, it was flown to the landing area, batteries were "hot swapped" and the UAS was launched and re-calibrated before continuing operations.

Figure 9. VT HAZMAT Response Team operating the UAS platform (left) and team members viewing the controller during UAS operations (right).

1.1.3.3 Multispectral Mapping

Multispectral mapping was conducted by personnel from the UVM UAS Team. A WingtraOne Gen II UAS platform was utilized for its ability to launch and land in confined areas and carry out efficient automated mapping operations. The platform was equipped with a MicaSense RedEdge-P multispectral sensor to collect multispectral imagery. The RedEdge-P sensor captured 5-band imagery (blue, green, red, red edge, near infrared), enabling the generation of multispectral maps and indices. The DJI Matrice 300 RTK with MicaSense Altum-PT sensor was brought as a backup platform, though it was not needed during operations. While the Livestream Team and VT HAZMAT Response Team were beginning UAS operations, the "Mapping Team" RPIC generated an automated UAS flight plan.

It was decided that the Wingtra flight plan would be generated in the field to allow for more informed decisions about where to place the home point and how far to extend the flight area based on information from the GRS Team. The flight plan was generated in the WingtraPilot application and covered the intended oil boom deployment, including slightly upstream and downstream to capture any hypothetical material movement (Figure 10). Flight height was set at 118 meters (387 feet) AGL to improve efficiency and allow for easier line of sight above nearby trees. The front and side overlap between image capture was set to 75%, a recommended amount to enable successful post-processing. The basemap and elevation data for the general mapping area were loaded using an internet connection to the Starlink system.

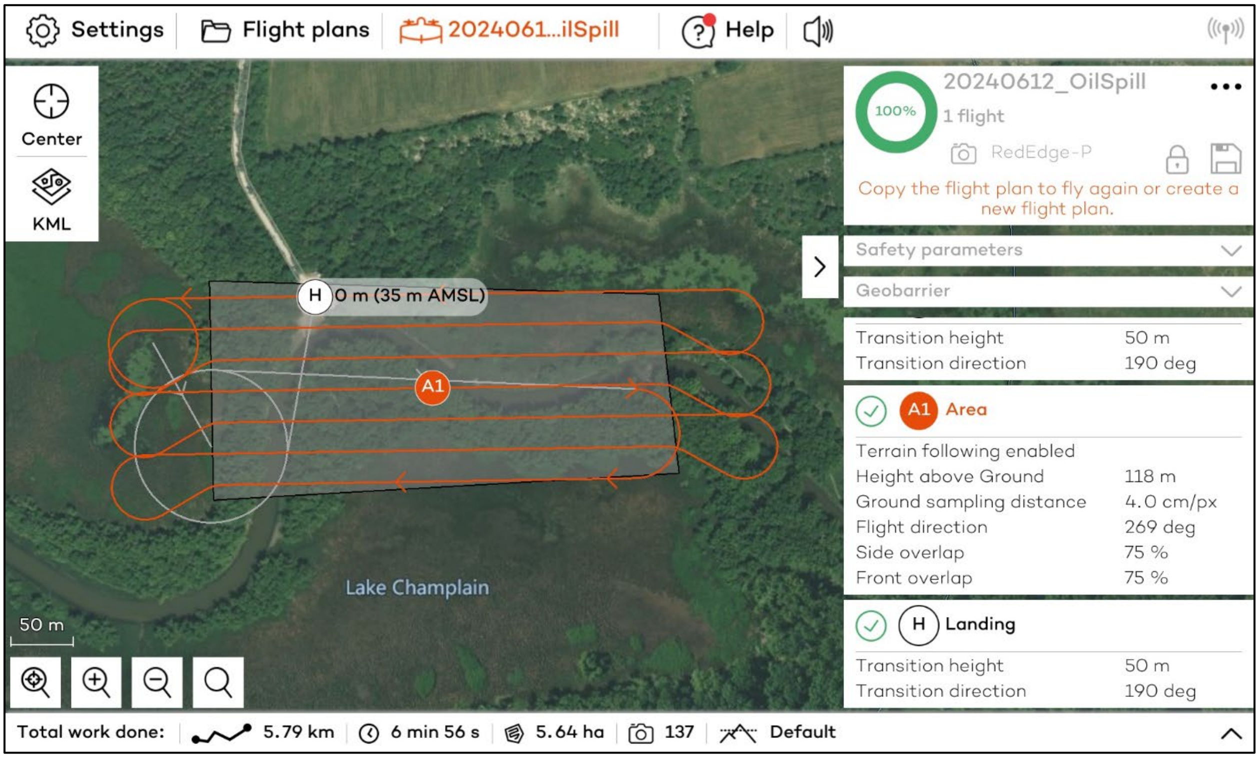


Figure 10. Wingtra flight plan in WingtraPilot. The "H" circle represents the "home" or launch/land area, the grey line represents the takeoff and landing approach, and the orange lines represent the path of the UAS as it collects imagery data.

The Mapping Team conducted pre-flight checks using detailed checklists to confirm that the area was clear of obstructions, RPIC and VO locations were assigned, communication methods were functioning properly and that the platform and sensor were ready for flight. The WingtraPilot application also guides users through an internal checklist to verify that hardware and software are operational. During the WingtraPilot checklist the payload could not be detected, which required the platform to be power cycled to resolve the issue. Before takeoff, an image of a calibration reflectance panel was manually captured, which enabled radiometric calibration during processing. Radiometric calibration improves spectral values of multispectral imagery. The initial set-up for the mission, including flight planning and pre-flight checks, took approximately 20-30 minutes. Once ready, the Mapping Team coordinated the UAS launch by confirming that the livestream platform and gas sensor platform were hovering at safe locations and clear of the automated flight path. The Wingtra was sent on its automated flight path at 09:49 EDT, initiating a vertical launch and then transitioning into fixed-wing flight (Figure 11).

Figure 11. Wingtra UAS platform launching vertically to begin automated flight path for multispectral imagery collection. VT HAZMAT Response Team's DJI Matrice 350 RTK visible in the top right corner of the image.

The UAS platform followed the predetermined flight route and automatically captured images. The RPIC and VOs closely monitored the airspace and communicated with the other RPICs to ensure deconfliction between all UAS operations. Communication was conducted via hand-held radios or direct conversation when in proximity. The multispectral mapping mission took approximately 7 minutes. Once the mission was complete, the Mapping Team announced the return of the UAS to land and confirmed that the landing zone was clear. Once the UAS landed and the images were saved onto the platform's memory card, the UAS was powered off. The CFexpress memory card was removed from the platform and images were copied locally onto a Dell Rugged field laptop. Images were checked to verify that all bands were captured and that there were no issues with quality, such as blurriness. To test the functionality of data processing in the field, the mapping images were uploaded to Pix4DFields photogrammetry processing software on the field laptop (Figure 12).

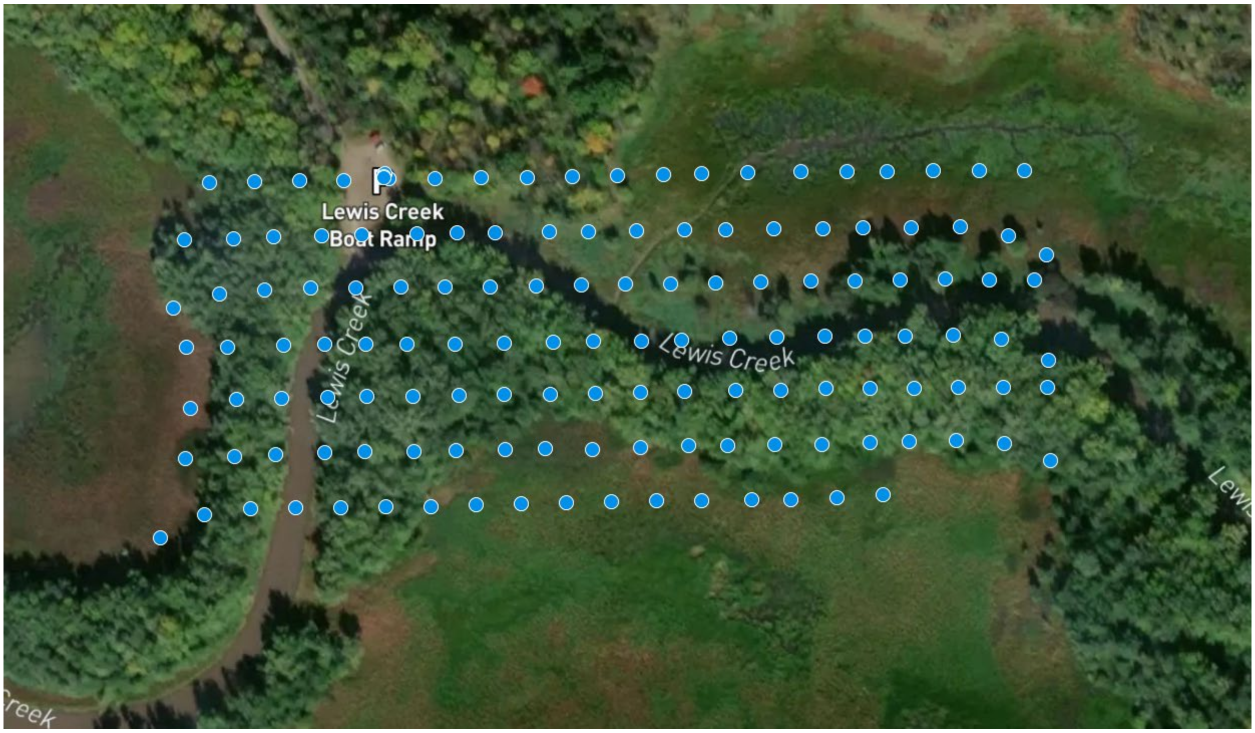


Figure 12. Image processing project set-up in Pix4Dfields. Blue dots represent where images were captured and are overlaid satellite basemap imagery.

Although the Wingtra has Post-Processing Kinematic (PPK) image positioning capabilities, the images did not undergo positioning corrections. This simplified the post-processing workflow in the field and allowed for quicker review and analysis of the scene. Accessing the software and setting up the project took approximately 15 minutes, processing the multispectral orthomosaic took about 10 minutes, and exporting the orthomosaic as a TIFF file took about 3 minutes. This relatively fast workflow (under 30 minutes in total) to generate approximately 14 acres of imagery, allowed for review of the UAS imagery products on site. In a real-world scenario, it would likely be beneficial to conduct additional mapping missions to assess the movement of hazardous materials.

1.1.3.4 Aerial Imagery and Video

Following completion of the mapping flight, personnel from the UVM UAS Team manually operated a small multirotor DJI Mini 3 Pro UAS. This platform was selected for its small size, relatively quick set-up and ease of use. The goal of this operation was to capture oblique photos and videos of the exercise area and flights began at 10:15 EDT. This content provided additional context to the scene, documentation of the event and was easy to share with stakeholders. Figure 13 and Figure 14 depict images captured with the small multirotor UAS and provide broader context, as well as detailed views, of the exercise.

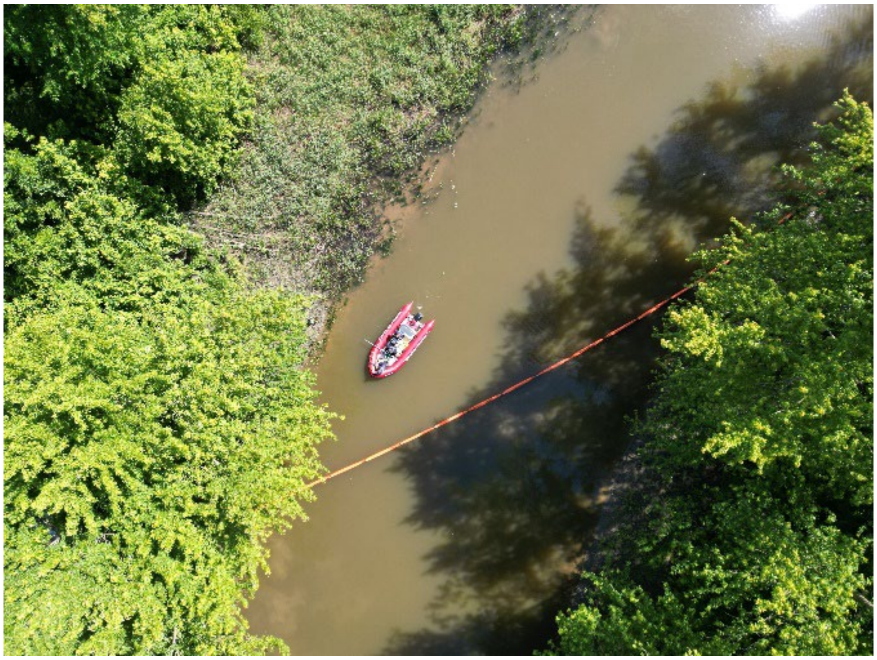


Figure 13. Aerial view of the oil boom deployment in Lewis Creek, captured by small multirotor UAS.

Figure 14. View of the functional exercise location in reference to Lake Champlain, captured by small multirotor UAS.

After capturing images and videos, the DJI Mini 3 Pro was landed, and the data was copied locally onto the UVM UAS Team's Dell Rugged field laptop. Oblique image sharing was tested using the Flight Events Tool developed as a part of A62. The Flight Events Tool allowed for the imagery to be rapidly shared to AGOL, where stakeholders could easily access the UAS data.

1.1.4 Oil Spill Response Functional Exercise Follow-Up Activities, If Applicable

Throughout the exercise, there was consistent effort to communicate any challenges or successes, take note of any questions that arose, and capture lessons learned to later debrief and review best practices. After the completion of UAS flight operations, there was an on-site, informal debrief amongst the UVM UAS Team and VT HAZMAT Response Team to check that the desired data was captured and that UAS operations were complete.

On the afternoon of June 12, following the oil spill exercise, the UVM UAS Team conducted an internal debrief meeting focused on reviewing the exercise's outcomes, discussing challenges encountered and identifying areas for improvement to enhance future response efforts.

Where applicable, all teams were responsible for their own data storage, processing, and dissemination. The Livestream Team saved and downloaded the recording of the Microsoft Teams meeting but had no further plans to process or disseminate the video, as the main purpose of the livestream was to test its utility during the exercise. In a real-world scenario, a livestream video recording could be used after a response to document the response, analyze different aspects of the response efforts, or help inform planning for future events. The VT HAZMAT Response Team was able to review their gas monitor readings in the field to confirm the functionality but did not have any follow-up activities to further analyze the readings. Following an actual oil spill response, such gas measurements could provide detailed documentation of on-site conditions or support long-term hazard monitoring after an event.

Once the UVM UAS Team returned to the UVM Spatial Analysis Lab, the multispectral orthomosaic that was processed in the field was shared. UVM UAS Team personnel copied the orthomosaic file, adjusted the file name to match their existing conventions and then copied it to a designated “deliverables” folder on a shared network drive. The orthomosaic file was then imported into an ESRI ArcGIS Pro project. The layer was duplicated so that the product could be displayed as both true-color and as a false color composite; One layer was symbolized with red, green and blue bands and the other was symbolized with near-infrared (NIR), red and green bands (Figure 15). A false color composite can help features of interest visually stand out that might be otherwise hard to detect. It was unknown what combination of bands might assist in identifying a hazardous material in water, but a color-infrared composite with the NIR band is a common choice in remote sensing when investigating landscapes.

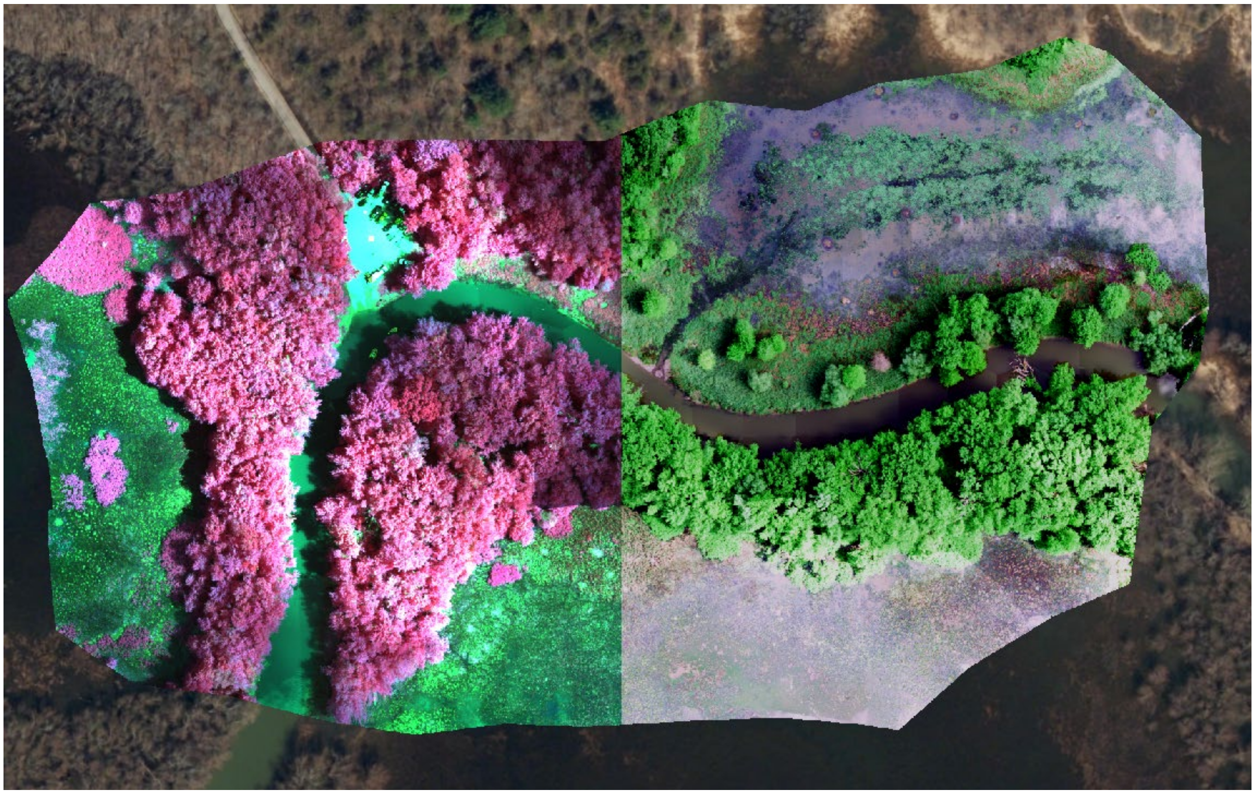


Figure 15. Comparison of the UAS imagery displayed as false color composite (left) and true color (right).

Both orthomosaics were then published to a tile service. Publishing the tile services to ESRI ArcGIS Online (AGOL) took less than 30 minutes. Once in AGOL, these items were added to a web mapping application containing the true color, multispectral and near-infrared maps, their associated legends, and analysis and viewing tools such as swipe or measure (Figure 16). The data products and mapping application were enabled for public access, allowing any user to view the products using a simple web link.

Figure 16. AGOL mapping application, showing multispectral orthomosaic displayed as a false color composite with the NIR, Red and Green bands.

1.1.5 Lessons Learned from the Oil Spill Response Functional Exercise, Including Responses to Research Questions

1.1.5.1 Oil Spill Response Functional Exercise Key findings:

- The response site, especially if it is serving as a center for a variety of operations, could have limited area for vehicles, personnel and equipment, thus limiting space for UAS missions.
- When responding to a scene in a public or common area, there are a variety of challenges that could arise including non-participants entering the flight area or increased activity that can be distracting for pilots and visual observers.
- EPA representatives stated that they could not directly task sUAS to be involved in this exercise. This impacted the integration of sUAS resources and data products within the GRS.
- During joint operations, communication between ground crew and UAS operators is crucial to ensure the most useful data is collected. Leading up to and during the exercise, there was somewhat limited communication and coordination between the GRS Team and UAS operators, creating a disconnect between the operations. This likely stemmed from lack of knowledge surrounding each other's operations and a narrow focus on the task at hand for each individual team, in addition to the challenges noted in the previous finding.
- While direct communication between UAS flight teams resulted in successful airspace deconfliction, a designated air boss might have provided increased clarity around timing

of UAS operations, improved the efficiency and allowed pilots and VOs to remain focused on their own operations.

- Sharing of the same launch and land zone(s) (LZ) amongst UAS teams makes it more challenging to ensure UAS are out of the way during the start or end of flights, resulting in the need for increased communication and coordination.
- A multirotor UAS equipped with an EO sensor that can rotate on its gimbal and provide a live feed is ideal for providing situational awareness.
- A live video stream of UAS operations and the surrounding scene has the potential to be a valuable resource for folks on the ground or at operation centers but may be underutilized if potential end-users are not made aware of its capabilities.
- There are barriers to successful implementation of livestreaming, such as cost and accessibility of applications, device compatibility and internet connection, among others. During the exercise, only one UAS was compatible with the video streaming app and internet connection was required which could prove challenging when attempting to standardize procedures across differing scenarios and response efforts.
- Recording a livestream of UAS operations may be beneficial for review afterwards, but more defined regulations regarding data retention and sharing would clarify and improve procedures.
- At the time of this exercise, it was identified that additional research was required to establish best methods for integrating a pipe for gas intake, where to place the gas sensor to limit interference from propellor blades, and how to access a direct stream of readings from the gas sensor back to the control station. There is a need for an affordable and simple gas sensor integration into UAS operations, as a retrofitted set-up can be challenging and cumbersome to fully integrate and operate.
- Depending on the response type, careful and controlled manual flight could be needed to operate UAS with a gas sensor.
- A VTOL platform excelled at launching from a confined area and carrying out an efficient mapping mission.
- It is not necessarily known to a UAS operator how much area upstream or downstream from an oil spill would be useful to map, requiring background knowledge before deployment or expertise from other responders on site to ensure the correct area is being captured during flight operations.
- Similar to the above finding, it is not known at what point throughout the boom deployment or response efforts would be most beneficial to have mapped with multispectral imagery. For example, should mapping occur as soon as possible following the spill, during the boom deployment or mitigation techniques, afterwards to measure the effectiveness of the response, or some combination of the three?
- A specific combination of spectral bands would be required to best visualize and identify oil or other hazardous materials in the water or surrounding environment, requiring knowledge or expertise about what type of multispectral data to collect and how to symbolize it before dissemination.
- Depending on the time of day, harsh lighting conditions and shadows can impact the quality and interpretability of mapping products. If the situation is time-sensitive, however, it will

not be possible to pick and choose when to collect imagery, potentially creating a challenge when it comes to post-processing and analyzing the UAS data products.

1.1.5.2 Oil Spill Response Functional Exercise Recommendations:

- When possible, robust analysis of the mission's site considerations (terrain, parking, public access, openness, etc.) during pre-deployment planning can aid in selecting a location that is viable for UAS operations. When it is not possible to choose the location, site analysis can assist in preparing accordingly for the site, such as limiting vehicle usage for confined areas or bringing cones and closure signs to block off public access. In the case of rapid response, consider utilizing stationary resources and personnel in primary office to evaluate site and provide guidance to strike team in field.
- When responding to a scene in a public or trafficked area, closures of the space could be coordinated to limit non-participant access and keep personnel and the public safe during operations.
- Collaboration between ground response crews and UAS operators can be challenging to promote and prioritize during emergency response, requiring further research and development of best practices to ensure each group is knowledgeable and aware of how to best support each other.
- During complex operations, consider using an "air boss" to assist with airspace partitioning and deconfliction to allow pilots and VOs to remain focused and operate more efficiently. Further studies into the use of a designated air boss would be helpful to identify what size and type of response would most benefit from the role, or in which scenarios would it be unnecessary.
- To avoid the challenge of other UAS occupying the launch and land zone at the start or end of flights, designate separate launch/land zones for each UAS Team with a safe buffer in between.
- When selecting a platform and sensor combination for providing situational awareness, choose a platform that can hover and manually maneuver, is equipped with an EO and/or IR sensor, can rotate the gimbal to see a variety of viewpoints from one location and can stream back a live view or feed. Consider application of a tethered sUAS for this task to minimize downtime.
- When conducting a UAS video livestream of a response scene, ensure the intended audience or potential end-users are aware of the resource and how to access it. Further research is needed to understand how ground crews or operation centers can best communicate their needs to UAS pilots and what possibilities exist for utilizing UAS livestream to supplement other operations or decision-making.
- Further research and development of low-cost, accessible and widely compatible livestreaming methods are needed to expand and standardize the capabilities of UAS aerial video streaming across differing scenarios and response efforts.
- The establishment of clear regulations or policy recommendations regarding UAS data retention following an emergency response is needed to clarify procedures for UAS pilots and their organizations, improve data storage techniques and limit legal or ethical questions.
- Further research and development are needed for an affordable and simple gas sensor integration into UAS operations

- Hands-on flight training and experience with manual flight operations are necessary for a pilot to feel comfortable operating a platform and sensor combination prior to a deployment. Training flights, drills and exercises and credentialing methods could all be utilized to ensure pilots are equipped with manual flight skills before an emergency occurs.
- When selecting a platform and sensor combination for a mapping operation from a confined area, choose a platform that can takeoff vertically and conduct imagery collection in an efficient manner.
- Further research and development are needed for standardizing best practices for UAS operators following an oil spill, including but not limited to:
    - What combination of spectral bands would be required to best visualize oil or other hazardous materials?
    - How much area upstream or downstream from a spill would be useful to map?
    - At what point throughout the boom deployment or response efforts would be most beneficial to have mapped with multispectral imagery. For example, should mapping occur as soon as possible following the spill, during the boom deployment or mitigation techniques, afterwards to measure the effectiveness of the response, or some combination of the three?
- UAS pilots should become familiar with potential lighting conditions or environmental factors that may impact the quality and interpretability of mapping products so that the best decisions can be made during capture. If needed, post-processing techniques such as adjusting brightness or contrast should be used to improve image quality and increase the interpretability of the UAS data products before dissemination.

1.1.5.3 Oil Spill Response Functional Exercise Informed Research Question(s):

1. How effective are the policies, procedures and guidelines used in the exercises?
2. When a disaster or emergency happens, what should future coordination with federal governmental agencies look like when UAS are fully integrated into the NAS?
    - There needs to be rapid and explicit tasking for UAS operators from federal agencies (or their collaborators), with a clear understanding of how the data products will be used and who the end-users are. Standard knowledge on which federal agencies can tasking/request sUAS support would be valuable.
    - Funding for UAS operations from federal government agencies before, during and/or following a disaster or emergency would potentially expand capabilities and allow for more widespread response efforts.
    - Remote ID and other UAS tracking efforts should allow other pilots (occupied or remote), members of response teams, or other stakeholders to identify UAS platforms and manage or deconflict airspace as needed.
    - During joint operations, there needs to be clear communication and collaboration between ground response and UAS teams.
    - Protocols should be in place to allow for ease of UAS data storage, dissemination and analysis between UAS organizations and federal agencies.
3. What are the considerations of disaster and emergency UAS Traffic Management (UTM) during manned/unmanned joint operations?
4. What are the considerations of evolving cyber security?

5. What UAS-related technological advances will benefit the use of UAS in a disaster or emergency response?
    - A livestreaming capability that is built into the UAS controller or flight application, allowing for easy set-up and sharing of video streams.
    - Simple gas sensor integration with communication between the payload and UAS, allowing for readings to appear live on the controller, flight application, or external device at the control station.
    - Development or training on sensors or indices geared specifically towards oil or hazardous spill mapping.
6. What are the barriers to entry for local, state and federal organizations employing UAS technology for disaster and emergency response and recovery?
    - Lack of funding to start up a UAS program, acquire equipment, train pilots, etc.
    - Difficulty around access to (and understanding of) UAS that are approved for the organizations' specific requirements.
    - Volunteer basis for UAS pilots, limiting training and response time.
    - Insufficient tasking protocols and failure to clearly identify UAS needs.
    - Limited knowledge around best practices, procedures and policies.
7. What enabling technologies or advancements would aid future disaster preparedness and emergency response?
8. What data should be gathered to support lessons learned and process improvements?
    - Whether or not oil spills typically occur near densely populated areas. This would determine if UAS that are approved for operations over people (OOP).
    - How often UAS responses to hazardous spills are paired with ground operations and in what way. Information about this type of collaboration would benefit coordination and communication efforts between ground and aerial teams during future responses.
    - What size and types of responses have benefited from having a designated "air boss" to assist with airspace partitioning and deconfliction. Knowledge surrounding the success of this role would inform when to deploy this type of position during a response.
    - What gas monitoring sensors are currently on the market, how easily they integrate into common UAS or blue-approved platforms and what type of gases they can detect.
    - What are the best practices regarding mapping coverage and timing to capture oil movement and which band combinations excel at visualizing the substance in the water or surrounding environment.
9. Propose future disaster preparedness and emergency response certification standards.
    - Certification standards for proper training and knowledge of hazardous material monitoring via UAS.

1.1.5.4 Oil Spill Response Functional Exercise Lessons Learned Summary:

UAS provide numerous valuable capabilities in responding to oil spills, as demonstrated in this functional exercise. Collaboration between regional agencies and the UVM UAS Team allowed for robust testing of UAS operations during the mock oil spill, and helped identify knowledge gaps in policies, procedures, guidelines, best practices and coordination.

An initial challenge during the exercise was the limited space in the response staging area, which highlighted the need for thorough pre-deployment planning and analysis of site considerations when possible. Before deployment and on site, UAS operators would have benefited from increased communication and coordination with personnel involved in the GRS operations. In this exercise, the lack of communication caused a disconnect between the GRS oil boom deployment and how the UAS team could best support their efforts. During emergency events, this disconnect could be avoided by establishing a clear understanding of each other's operations and encouraging direct communication throughout the response.

Airspace partitioning and communication between UAS teams was crucial to successful airspace deconfliction and mitigating risks of simultaneous UAS operations. Radio and verbal communication between pilots and visual observers were successful, but there is further research needed to establish when a designated air boss may be necessary. The selected UAS proved instrumental in carrying out the mission type and objectives, but there are associated knowledge gaps that remain, especially around standardizing methods and best practices, as well as sensor integration. Continued connection, collaboration and training is needed amongst agencies to improve best practices and continue to develop the appropriate protocols for UAS response to an oil or hazardous material spill.

1.2 07/11/2024 – 07/13/2024, Hurricane Beryl Flood Response Event, Washington County Vermont, Conducted by the Univ. of Vermont (UVM)

Hurricane Beryl's remnants hit Vermont on the night of July 10 and into July 11, 2024. The storm caused rapid water-level rises in rivers such as the Winooski, Passumpsic, and Lamoille, with some areas experiencing over 7 inches of rain. The most severe impacts occurred across the center of the state, with cities and towns in Washington County being critically impacted as they continued to recover and rebuild from the Great Vermont Floods of July 2023. By the morning of July 11, Type III Urban Search and Rescue (USAR) and Swiftwater Rescue teams had carried out more than 118 active rescues, 12 evacuations, and 16 pet evacuations. The Vermont Agency of Transportation (VTrans) determined that more than 100 bridges across the state were damaged, and 185 miles of Vermont state roads were closed due to the flooding.

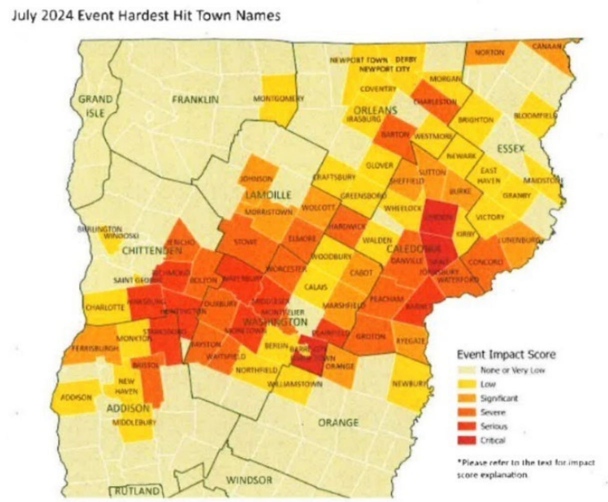


Figure 17. Concentration of storm impacts as reported by State Local Liasons.

The real-world response events carried out by UVM in Barre City and the Town of Plainfield are highlighted in this report as two particularly illustrative case studies. Both communities suffered similar damage during the Great Vermont Floods in 2023, which drained their financial reserves and limited their capacity to respond to the impacts of this storm. Though not highlighted in reporting for the ASSURE A52_A11L.UAS.68 project (Disaster Preparedness & Recovery for UAS Phase II), UVM did carry out flight operations in both locations as part of the response efforts in summer 2023. This makes both locations of significant interest investigating new use-cases and unexpected challenges faced during the 2024 response efforts and allow for unique comparisons of the flood event impacts between July 2023 and July 2024.

Figure 18. Statewide distribution of sUAS datasets captured during response to July 10-11, 2024 flood events.

UVM's contributions to flood response following the impacts of Beryl expanded far beyond the efforts in these two locations. In total, UVM completed 143 sUAS flights between July 11 and July 22 in response to requests for support across the state. The tasking and execution of these missions included capture of oblique aerial imagery, aerial video, and mapping data such as 2D true-color orthoimagery and 3D UAS-LiDAR elevation products. These flights resulted in the generation of over 1 terabyte of raw and processed data products during this period.

1.2.1.1 Barre

In Barre, the Winooski River exceeded flood stage in the early hours of July 11. Severe flooding caused the Stevens Branch of the Winooski River to overflow, inundating homes, streets, and businesses. Residents faced thick mud and debris in downtown areas and infrastructure was heavily damaged. Similar to the flood events of 2023, a series of small landslides occurred around the city's steep topography. A State of Emergency was declared in Barre around 17:30 EDT on July 10, after officials rescued more than a dozen residents from flooded homes and vehicles.

Figure 19. Flood debris and sediment covering Barre City.

1.2.1.2 Plainfield

Plainfield experienced catastrophic flooding of the Great Brook, which destroyed multiple homes, a dozen bridges and culverts, and cut off access to vital roads, leaving the community isolated. The collapse of a concrete bridge in the center of town was likely responsible for ripping off part of a 5-unit apartment building, from which the residents had only 15 minutes to evacuate before it was swept away by floodwaters. Nearly every of the 47 landslides previously identified by the Geologic Division of VT DEC in the town was reactivated, causing heavy damage to the community and town infrastructure. One landslide in Plainfield was deemed as unstable, with mitigation and monitoring required. The town suffered major damage to drinking water supplies and wastewater treatment facilities and as one of the State's most severely impacted towns during this storm, Plainfield declared a State of Emergency on July 18, 2024. Local officials have estimated that the town suffered up to $15 million in damages, which will cause challenges in the recovery process for a town with an annual budget of just $1.3 million.

Figure 20. Storm damage in central Plainfield, including loss of downtown bridge and apartment complex.

1.2.2 Objectives of the Flood Response Event

The aim of these response operations was to deploy UAS to support urgent and immediate flood response and recovery efforts in severely affected areas across Vermont. Additionally, this response offered an opportunity to assess the UVM UAS Team's procedures, capabilities, and limitations, as well as processing and dissemination activities, while also capturing lessons learned and best practices for future efforts.

1.2.2.1 Barre

The objectives of the UAS response operations in Barre were to collect UAS imagery, video, and mapping data in order to document and identify flood-related damage across the city. The city was severely impacted by the Great Vermont Floods of July 2023, during which UVM provided a similar response, proving the value of rapid aerial imagery to the city's Fire Chief and Emergency Managers.

1.2.2.2 Plainfield

The objectives of the UAS response efforts in Plainfield focused on the capture of aerial imagery, video, and mapping data for documentation, in addition to the collection of highly detailed elevation information. The Great Brook in Plainfield has been studied for decades as a powerful and dynamic waterway and continued studies into the impacts of the latest flood event were considered critical to improve the town's resiliency in the face of future weather events. UVM has captured orthoimagery of the Great Brook dating back to 2015 and captured elevation and imagery following the floods of July 2023. These datasets provide tremendous comparisons to understand the full impact of the storms, the movement of woody debris within the stream channel, and to inform the town's recovery efforts.

1.2.3 Planning for and Logistics of the Flood Response Event

On July 9, UVM became aware that there was potential for flooding and severe impacts from the incoming storms and began the internal stand-up process to prepare for expected UAS operations. UVM's UAS Program Lead contacted the VTrans UAS Program Manager with the notification that UVM would be on call to support response efforts as required.

The experience gained during UVM's flood response efforts in summer 2023, in support of A52_A11L.UAS.68 project objectives, served the organization well in their ability to prepare for an imminent weather event. Significantly, the loss of the UVM SAL's Director in January 2024 resulted in the UAS Program Lead taking on a leadership role in organizing the preparation for response efforts. The ability to step into such a role would not have been possible without drawing on the experience gained and state-wide connections made during the summer 2023 response operations. The UVM Program Lead scheduled an internal briefing and directed UVM personnel to prepare for UAS operations in coming days. As a result, staff from the UVM UAS Team spent the afternoon of July 10 charging batteries, completing pre-mission equipment checklists, and readying nearly every sUAS platform, associated sensor packages, and supporting equipment to allow for an expected timely response. The UVM Program Lead continued to contact other personnel within state agencies in the early morning hours of July 11, including the Director of the Vermont Center for Geographic Information (VCGI) and Director of the Geologic Division of VT DEC. Tasking was also relayed to UVM through the activated State Emergency Operations Center (SEOC).

1.2.4 Flood Response Event Execution

1.2.4.1 Barre City

The Barre City Fire Chief submitted a request to the State EOC at 23:35 EDT on July 10 requesting aerial imagery of all of Barre City and extending east to the Orange Reservoir. This request was relayed to the VTrans UAS Program Manager at 08:00 EDT on July 11. He then proceeded to call the UVM UAS Program Lead, asking if he would be able to pass this request to UVM. Due to the close working relationship between the program managers, staff at VTrans were aware of UVM's sUAS platforms and capabilities and was aware that UVM maintained sUAS that were compliant for OOP and suited to large-scale mapping, a task that his organization did not have the capacity for.

After the call from VTrans, UVM prepared and charged gear, and a team briefing was held at 08:45 EDT. The internal team brief covered tasking, other preparation tasks such as generating flight plans, and response logistics. Flight plans from the July 2023 flood response in Barre were utilized to reduce time required for flight planning and inform launch and landing locations. Flight areas were broken into blocks that included downtown Barre, a corridor over Route 302, and the Orange Reservoir (Figure 21).

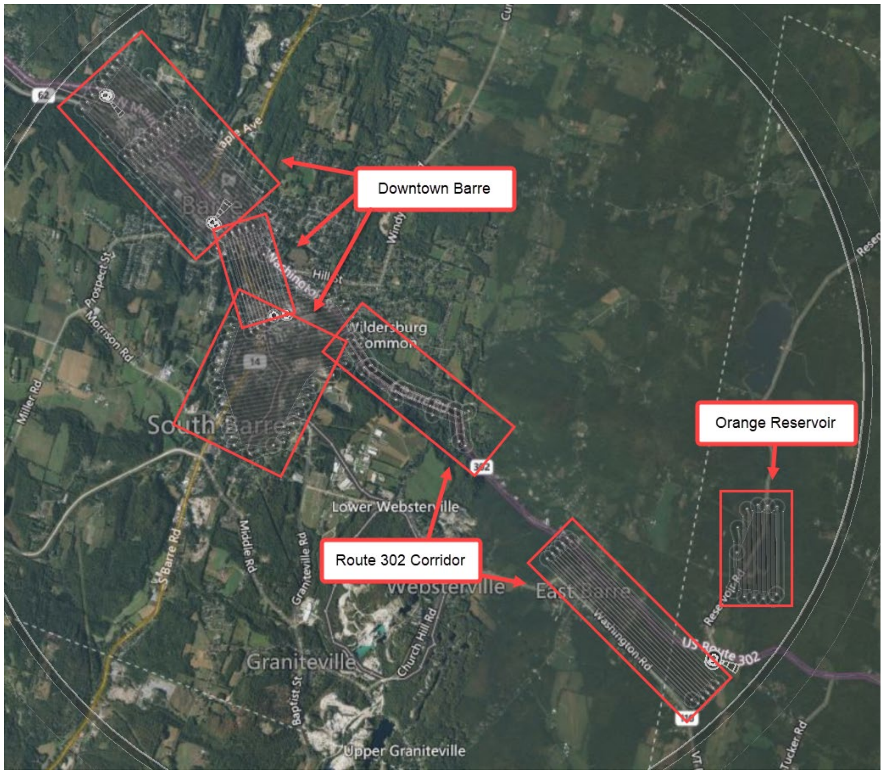


Figure 21. Initial flight planning blocks for mapping Barre.

Nearly all of downtown Barre City lies within the Class E airspace of nearby Edward F. Knapp State Airport (MPV), which limited the altitude of flight operations with airspace authorization to between 100 – 400 feet AGL with Low Altitude Authorization and Notification Capability (LAANC) approval. To allow for the most efficient mapping operations over the city, UVM planned to conduct operations between 390-400 feet AGL. As a result, it was determined that VTrans and UVM would utilize the Special Government Interest (SGI) process to receive expedited airspace authorization, similar to the process that was utilized when flying in this area during the July 2023 flood event.

A UVM staff member drafted a SGI request form, which was emailed to the VTrans UAS Program Manager at 10:35 EDT. VTrans called the FAA's System Operations Support Center (SOSC) upon reception to explain the SGI request. On this call, SOSC informed VTrans that UVM would need to submit the SGI request directly to the SOSC if they were the organization that would be operating UAS. The SOSC representative advised VTrans that their office was understaffed with only one person available per shift and that the impacts of Hurricane Beryl across Texas and the south had resulted in a delay in processing SGI requests. A request was made not to call the SOSC for status updates after submitting the SGI request due to the office's heavy workload. Additionally, since UVM is a public university, the SOSC advised VTrans that UVM should provide documentation on Vermont State letterhead confirming their tasking for such emergency sUAS operations when submitted the SGI request. This request was relayed to an Incident Commander with the VTrans Transportation Incident Command Center, who provided UVM with a suitable letter of support at 12:05 EDT. UVM emailed their SGI request and letter of support to the SOSC at 12:08 EDT. As displayed in Figure 22, the submitted SGI request identified two radii to define the flight areas required.

Requested Flight Details	
Enter the date(s) of the proposed UAS operation (e.g., 03/18/2018 or 03/18/2018-03/21/2018) Mandatory entry	
07/11/2024 – 07/12/2024	
Enter the times of the proposed UAS operation (be sure to confirm time zone; e.g., 1200L-1400L daily) Mandatory entry	
0600 – 2000 EDT daily	
Enter the location of the proposed flight (reference the nearest city or town, and state; e.g., Gulfport, MS)	
Location 1: Barre, VT Location 2: Berlin, VT	
Enter the distance and direction from the nearest airport, and FAA identification of the same (e.g., 6 NM W of GPT)	
Location 1: 2.5 NM E of MPV Location 2: 2.25 NM NE of MPV	
Identify the class(es) of airspace in which the flight will be conducted (e.g., Class G/E/D/C/B/A)	
Class E	
Requested altitude of UAS flight: Mandatory entry	
400 feet AGL	
Enter GIS details defining location of proposed flight (only one area type description needed) Mandatory entry	
For those flights remaining within a general contiguous area, which can be described as a circular polygon, provide the latitude and longitude, expressed as **degrees/minutes/seconds**, of the center of that area and the radius of that same area (e.g., XX:XX:XXN / XXX:XX:XXW - .25NM radius)	Location 1 (Barre): 44°11'48.79"N / 72°30'5.20"W - 2NM radius Location 2 (Berlin): 44°13'44.57"N / 72°32'29.73"W – 1NM radius

Figure 22. Flight details submitted by UVM to SOSC at 12:08 EDT July 11, 2024

Three UAS strike teams departed from UVM and arrived at the Barre City Auditorium around 12:45 EDT, where they spent about 45 minutes meeting with other responders to understand the situation and needs in the area. The Barre Fire Chief and city managers tasked UVM personnel with collecting UAS data of as much of downtown Barre as possible, as well as focusing on a reservoir corridor and impacted mobile home communities. The corridor went from downtown Barre to the Orange Reservoir, a drinking water source and critical infrastructure for the city.

Priorities for UAS data collection had to be adjusted slightly because the SGI was not approved and time was of the essence. At 13:30 EDT, UVM Strike Team 1 (UVM-1) deployed from the Barre City Auditorium to begin mapping the water treatment plant at Orange Reservoir, located southeast of Barre in Class G airspace. Strike teams UVM-2 and UVM-3 deployed to capture oblique images and video of impacted infrastructure and landslides in the Barre area. UVM-2 and UVM-3 obtained LAANC approval up to 100 feet AGL and collected imagery with two DJI Mini 3 Pro UAS of damaged infrastructure and local landslides while awaiting updates about the approval of the airspace authorization through SGI.

Figure 23. Debris caught in bridge and landslide in residential neighborhood, Barre, VT.

UVM-1 arrived on location at 14:15 EDT and finalized the flight plan to ensure it covered the entire AOI. The Barre Fire Chief had requested imagery of the reservoir, as well as up and downstream areas so that any leaks or debris buildup could be identified. A fixed-wing AgEagle eBeeX sUAS and EO camera were utilized for the mapping mission, which took approximately 25 minutes. RTK positioning was enabled during imagery collection by connecting to the Vermont Virtual Reference System (VRS) with a mobile hotspot. Upon completion of the mapping mission, a DJI Mini 3 Pro was used to collect oblique images of the reservoir and washouts on the nearby access road (Figure 24). The small multirotor flight also served to test VLOS for operations to the south of the reservoir. Due to inadequate visibility and other data collection priorities, the area to the south of the reservoir was not mapped.

Figure 24. Washout and road damage on the Orange Reservoir access road.

At 15:00 EDT, approximately 3 hours after submission, UVM had not received any update on the SGI process and contacted the SOSC by phone. The SOSC staff member indicated that their workload was high and that other priorities required more immediate attention, including VIP movement and law enforcement response to an active shooting event elsewhere in the country. At 17:00 EDT, SOSC followed up by phone to request adjustment to the SGI areas. The original request included a central point with a 2 nautical mile (NM) radius circle around it to cover all areas of interest. SOSC communicated that this area was too large and too close to the airport to be approved. UVM's UAS Program Lead generated a polygon covering the Barre City corridor and two 0.25NM radius circles for mobile home park mapping to specify a tighter boundary around the operational area requested. It was noted that this was not a user-friendly process, due to the SGI request form specifying that the coordinates of each vertex must be provided in text form, rather than by submission of a common geospatial file type (for example, KML or SHP). Google Earth was utilized to draw a polygon covering the operational area and the coordinates of each vertex had to be manually identified and recorded into the revised SGI request. The revised SGI was submitted at 16:52 EDT to the SOSC by email and approved at 17:37 EDT, about 5.5 hours after the original submission.

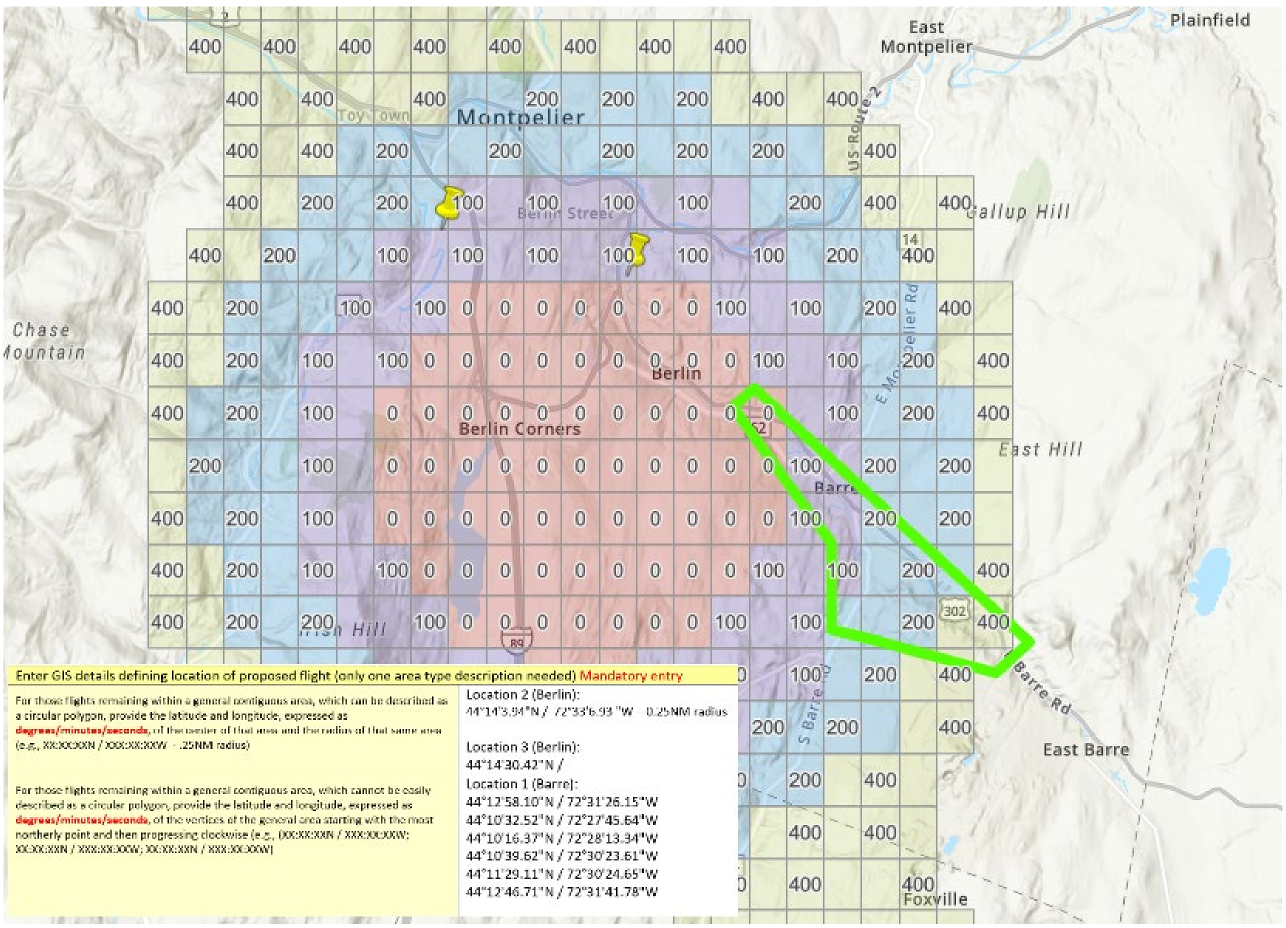


Figure 25. Revised SGI flight areas (green polygon and yellow pins) overlaid on MPV airspace cells. Inset displays coordinates defining flight areas.

At approximately 15:30 EDT, UVM-2 and UVM -3 completed collection at the identified locations. UVM-2 relocated to a site south of Barre, off Route 302, in order to map the section of corridor between the Orange Reservoir and downtown Barre (Figure 26). It was decided that mapping this corridor would start at the south end, because it was in Class G airspace and did not require the SGI approval. Corridor mapping was truncated due to VLOS limitations and finished around 18:15 EDT. Meanwhile, UVM-3 relocated to Berlin Mobile Home Community (MHC) for additional oblique captures while awaiting the SGI approval.

Figure 26. Orange Reservoir and Route 302 Corridor flight areas.

At 17:40 EDT, SGI approval was relayed by the UAS Program Lead to the strike teams, who were directed to begin capturing as much mapping data as possible before civil twilight. In addition to the Orange Reservoir, there were three other missions initially planned that would, when combined, cover downtown Barre. The three mission blocks over downtown Barre included one of the main downtown areas, one slightly north of downtown, and one covering northwest downtown (Figure 27).

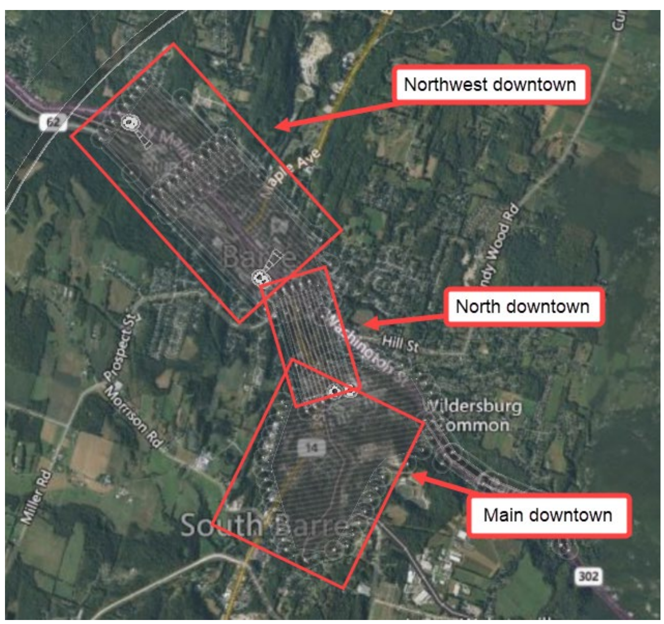


Figure 27. Downtown Barre mapping mission blocks: Main downtown, north downtown, and northwest downtown.

Although mapping downtown Barre was the highest priority, the delay in SGI approval meant that these areas were flown late in the day on July 11. While UVM-1 finished mapping the southern

Route 302 corridor, UVM-2 and UVM-3 established operations over the main downtown and north downtown blocks, respectively. Both flight teams operated AgEagle eBee X fixed-wing platforms with EO sensors, which were configured in compliance for OOP. This compliance was critical to allow for comprehensive mapping collection over the center of this small city, with a population exceeding 8,000 residents. Data collection of this type would not have been possible under Part 107 regulations without an OOP-approved platform or a waiver to allow for OOP. To maintain safety during simultaneous operations, the two strike teams coordinated the order and direction of which their mapping mission would be carried out. The main downtown mission began with the most southern flight lines, with the UAS working south to north to provide sufficient time for the shorter north downtown mission to be completed and the shared UAS airspace cleared. During this response, the two strike teams were not able to identify an adequate technological solution to maintain oversight on the position and trajectory of both UAS flying simultaneously across the city and relied on direct radio and cellular communications to relay information about the flight status.

UVM-3 operated from a parking lot along Merchants Row just north of the AOI and the mission took approximately 25 minutes from launch to land. UVM-2 operated from Spaulding High School Athletic Field and completed one 40-minute flight (approximately half of the planned main downtown mission) before it began to rain and the UAS was landed around 19:00 EDT. Due to the continued forecast for rain through the end of civil twilight, all UVM teams packed up their equipment and drove back to UVM campus. An internal debrief was held at approximately 20:00 and covered the day's accomplishments and preliminary tasking for the next day, July 12.

The UVM UAS Team held an internal brief at approximately 09:00 EDT on July 12 to review UAS response requests and determine priorities for the day. Two UVM strike teams (UVM-2 and UVM-3) deployed to Barre to finish the mapping that had been started the day before. Both teams arrived on site at 11:00 EDT and utilized AgEagle eBee X fixed-wing platforms with EO sensors, again configured in compliance with OOP regulations. UVM-2 returned to the Spaulding High School Athletic Field and finished mapping the main downtown Barre region. Strong and shifting winds made landing the fixed-wing platform very challenging at the end of the main downtown mission. Additionally, high humidity on the UAS platform's ground sensor caused inaccurate ground measurements, which negatively impacted the accuracy of the system's landing. UVM-3 started at the Berlin MHC to collect EO mapping imagery, but due to rain, shifted to complete data collection along the Route 302 corridor (Figure 28). One issue that arose during the Route 302 corridor mapping was that the camera lens fogged up due to the change in environmental conditions between the car and outside. It was later discovered that the fog impacted some of the imagery, though it was resolved by increasing contrast in a photo editing app before processing.

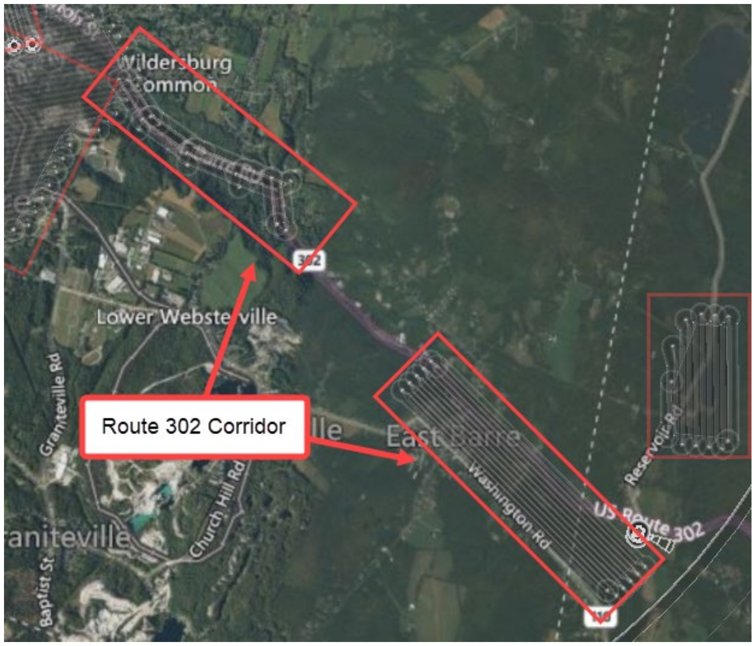


Figure 28. The Route 302 Corridor was split into 2 parts due to VLOS limitations.

Once finished with the main downtown region, UVM-2 relocated to the Granite Museum on the north side of downtown Barre around 14:30 EDT. This location provided a suitable LZ and VLOS for mapping part of the northwestern downtown, however, due to intermittent showers flights were paused to wait for the weather to pass. UVM-3 completed mapping the remainder of the Route 302 corridor at 15:45 EDT and rallied at the Granite Museum to provide support for flights over the city. With both teams at the Granite Museum waiting for the weather to pass, photos were attempted to be uploaded into AGOL using the A62 Flight Events Tool using a Starlink internet connection. Due to the large number of photos and slow upload speeds, the flight tool was unable to upload the images. Plans were then changed to head to the Berlin MHC to finish the collection imagery instead. At 16:15 EDT, UVM-3 relocated to the Berlin MHC to carry out a 10-minute mapping mission, while UVM-2 remained at the Granite Museum to complete 35 minutes of mapping. Both teams met around 17:00 EDT in an empty parking lot near the Opera House in downtown Barre to complete the last portion of the northwest downtown mapping mission. The flight ended around 19:00 EDT, at which point the team packed up all gear and returned to UVM campus. At the end of each flight throughout the day, data was copied from the UAS sensor to a field laptop. During the drive back, all teams joined a debrief call to review what had happened during the day and discuss future tasking. Once back at the lab, data was copied from the field laptops to UVM servers. In total, 29 individual flights were carried out in and around the City of Barre for this response event.

Figure 29. UVM-2 and UVM-3 conducting operations around 17:15 EDT on July 12 in downtown Barre.

1.2.4.2 Plainfield

On July 11, the UVM UAS Team received an email from state geologists and the Plainfield Emergency Manager requesting mapping support over Plainfield, VT. At 08:00 EDT, the UVM UAS Team held a briefing and began preparing equipment for data capture. It was noted that the entirety of the requested area was within Class G airspace. Using previous Great Brook data captures, including the flight plans utilized in July 2023, preliminary flight plans were created. The Great Brook was separated into 5 sections: western, downtown, north, central and south (Figure 30). The northern section of the Great Brook was split into multiple LiDAR flights due to the low flying nature of LiDAR flights and obstacles for line of sight. Due to the large area requested for data capture (exceeding 1200 acres over a 4-mile corridor), it was also decided that this mission would utilize two strike teams (UVM-1 and UVM-2). At 09:00 EDT, the team received official tasking from the SEOC to capture imagery and LiDAR of the Great Brook in Plainfield. Of note was that the request did not include the capture of oblique imagery and video of damage in the town, as this task had been carried out on July 10 by a UAS team from VTrans. UVM-1 and UVM-2 departed for Plainfield with the following configurations:

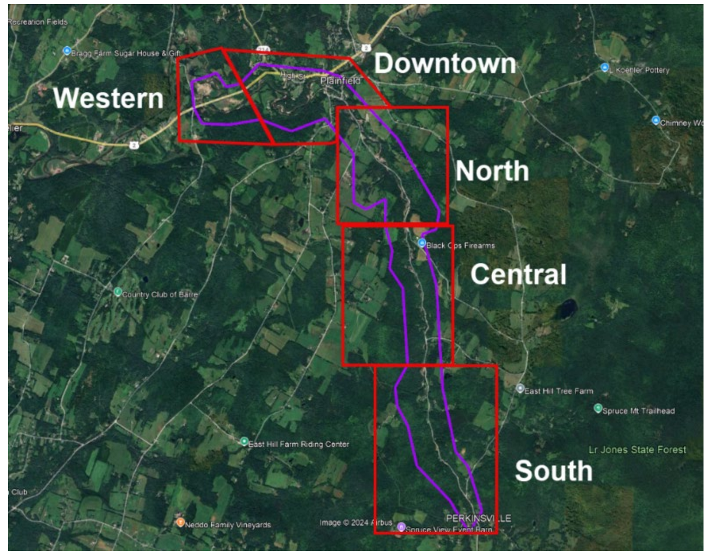


Figure 30. AOI of the Great Brook in Plainfield split into 5 locations: Western, Downtown North, Central and South.

- UVM-1
  - 1 RPIC, 1 VO
  - AgEagle eBee X with EO mapping sensor (OOP-compliant configuration)
  - WingtraOne Gen II VTOL with EO mapping sensor
  - Objective: Wide-area mapping imagery
- UVM-2
  - 2 RPIC, 2 VO
  - AgEagle eBee X with EO mapping sensor (OOP-compliant configuration)
  - DJI Matric 300 RTK with YellowScan Surveyor Ultra LiDAR sensor
  - Objective: Wide-area mapping imagery and UAS-LiDAR

At 11:00 EDT, both teams arrived at the designated meeting point just north of the town center, where the town Emergency Manager, a state geologist, and a town council member conducted a briefing with the strike teams. The teams planned to start at opposite ends of the Great Brook for UAS deconfliction. At 11:30 EDT, each team then headed to their tasked locations with a town member each to help with navigation and communication with landowners, which allowed for the selection and permissions to utilize suitable LZs extremely efficient and effective.

At 11:40 EDT, UVM-2 began operations over downtown Plainfield with a 53-minute flight of the eBee X at 400 feet AGL. Once again, the OOP-compliance of this system was critical in the team's ability to collect data over a populated town center. The M300 LiDAR capture began in series shortly after the eBee X completed its flight. The LiDAR flight required a battery swap midway through the flight plan took a total of 45 minutes between two subsequent flights at 200 feet AGL. Prior to operations, the town Emergency Manager and Town Councilmember had notified residents about the UAS operations and data capture. However, UVM-2 worked diligently to make strategic adjustments to the automated flight plan in order to avoid carrying out any UAS operations with the M300 that would at any time, including the possibility of a catastrophic failure, go over or strike a person not directly involved in the flight operation. This mitigation strategy included reducing the total mapping area for LiDAR compared to imagery and in particular, not flying directly over downtown Plainfield. In-flight decision making by the RPIC, supported by information relayed by the VO, also mitigated these risks by empowering the RPIC to pause, avert, or adjust the planned flight program according to the hazard.

Figure 31. A UVM RPIC consults with Plainfield Town Councilmember to develop an automated LiDAR flight plan.

At 13:30 EDT, UVM-2 completed flights in this area and relocated to a secondary location, west of Plainfield along VT Route 2, which was closed due to a damaged bridge. The road closure allowed for use of the road surface as an LZ for both systems and ensured that no non-participants or vehicles were within the mapping area. At 14:30 EDT, the UVM-2 began an eBee X flight to capture mapping imagery over western Plainfield at 400 feet AGL. Twenty minutes into the flight, small pockets of rain began falling and the PIC landed the UAS. Operations at western Plainfield resumed at 15:30 EDT, with the eBee X completing the remainder of the mapping mission in 35 minutes. At 16:00 EDT, the second PIC from UVM-2 began UAS-LiDAR capture in tandem with the last portion of the eBee X mission. The missions had vertical separation of approximately 170ft which allowed for safe operations in shared airspace. At 17:00 EDT flights at western Plainfield concluded and the UVM-2 relocated to the North mapping area.

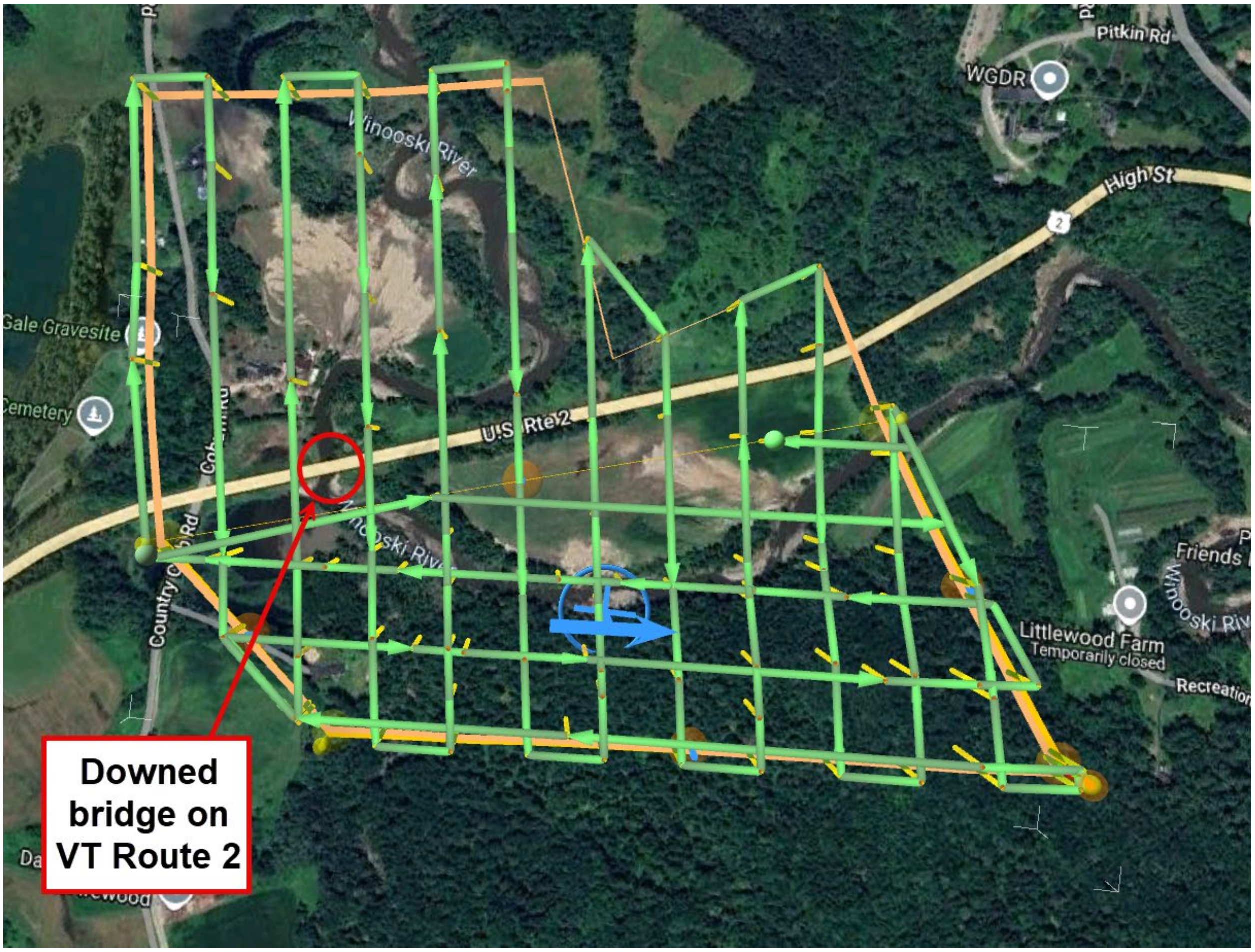


Figure 32. Flight plans of Western Plainfield noting the downed bridge on VT Route 2 which cut off traffic into Plainfield.

UVM-1 began flights in the southern portion of the Great Brook with an eBee X at 12:30 EDT. At 13:30 EDT, midway through the flight, a battery swap was required but due to the hilly terrain of the Great Brook, the eBee X crashed into shrubbery during the final landing approach and sustained damage to the wings. UVM-1 then swapped mapping platforms to utilize the WingtraOne Gen II in order to finish image capture over the southern portion of the Great Brook. At 14:50 EDT, the UAS was grounded and flight operations paused due to passing rain. At 15:30 EDT, UVM-1 resumed mapping operations and continued carrying out mapping missions moving from south to north.

At 17:30 EDT, UVM-1 and UVM-2 reached overlapping flight areas at the northern section of the Great Brook and the southern team at the central part of the Great Brook (Figure 33). Communication was established between each team via handheld radio to ensure airspace deconfliction. At 18:00 EDT, UVM-2 started a true-color flight with the eBee X at 400 feet AGL, beginning with the southernmost flight lines in the overlapping area. Once the overlapping flight lines had been completed, UVM-2 relayed this information by handheld radio to UVM-1, who began flights at 18:30 EDT with the WingtraOne Gen at 400 feet AGL for 50 minutes.

Figure 33. Overlap between flight areas of the northern and central sections of the Great Brook.

When both the WingtraOne and eBee X had completed their flights, UVM-2 carried out two UAS-LiDAR missions over this region. Flight operations concluded at 20:20 EDT and both teams returned to UVM campus. In total, five true-color mapping flights and three UAS-LiDAR flights were carried out, covering a collection area exceeding 1500 acres of orthoimagery and approximately 580 acres of LiDAR collection. At 20:50 EDT the teams arrived at UVM and uploaded the collected data to UVM's data servers.

Figure 34. UVM-1 operates WingtraOne VTOL UAS to capture mapping imagery in Plainfield.

1.2.4.2.1 July 18, 2024 UAS-LiDAR Collection

On July 18, 2024, a UVM UAS Strike Team returned to Plainfield to finish the collection of LiDAR over the AOI. The locations left for LiDAR collection included the second half of the northern, central and southern part of the Great Brook (Figure 35). The team consisted of 2 PICs and 2 VOs for support with the DJI Matrice 300 RTK platform and YellowScan Surveyor Ultra LiDAR sensor.

At 10:00 EDT, the team arrived on site. Local contacts in the town had pre-arranged permissions and access to LZ locations located on private property along the corridor. Due to the dense tree cover that covered the northern section of the Great Brook, VOs were dispersed throughout the corridor to provide additional support to the RPIC. The second RPIC on the team relocated to a secondary location along the corridor to provide the option to transfer flight control between RPICs if deemed necessary for operational safety. This is in accordance with Part 107 5.2.1.1 where transfer of control is permitted between certificated remote pilots if they are both capable of maintaining line of site throughout the flight without loss of control.

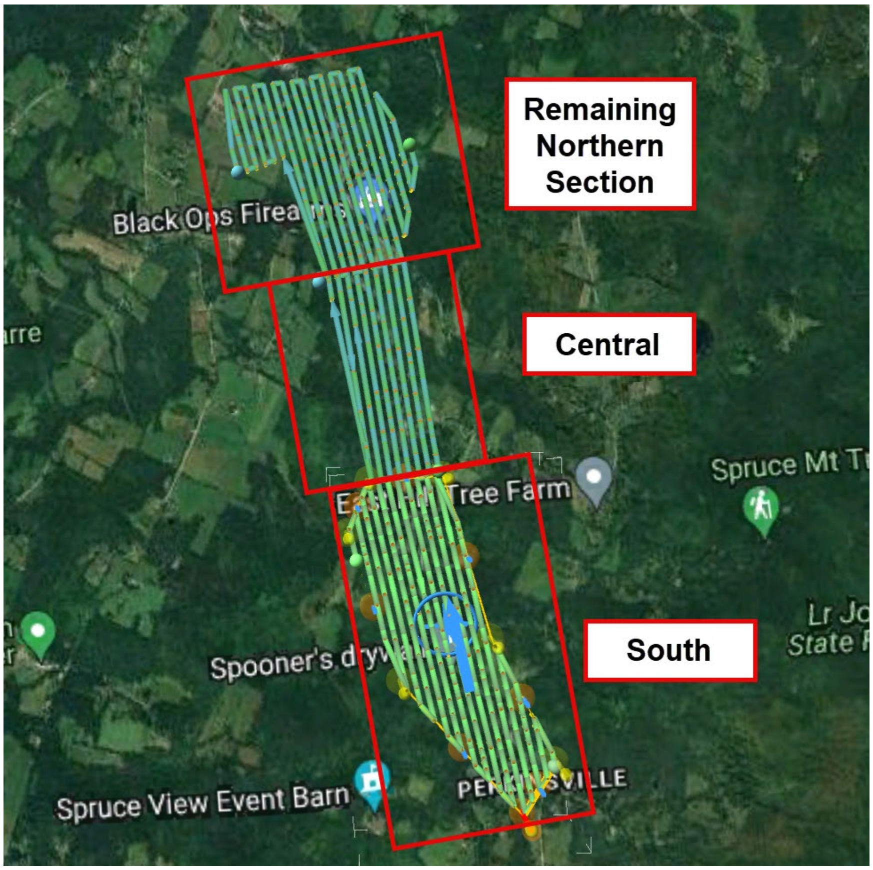


Figure 35. Flight plans for the remaining sections of LiDAR collected on July 18, 2024. Sections include: the remaining northern, central and southern sections.

At 10:30 EDT, the team began four subsequent UAS-LiDAR flights over the central section of the AOI. At 13:10 EDT, the team relocated to another LZ to continue the mission. Due to the hilly terrain of this section, RPIC and VO were located on a hill in order to maintain VLOS during the three subsequent flights, beginning at 13:45 EDT. At 15:00 EDT, these LiDAR flights concluded, and the team relocated to charge UAS batteries and supporting equipment at the Plainfield City Hall.

At 16:30 EDT, the team relocated to the southern section of the AOIs. The LZ was located at the top of a hill, allowing for VLOS throughout the missions. Six subsequent flights were carried out, spanning 1 hour and 22 minutes. All flights were completed at 17:50 EDT, completing UAS-LiDAR data collection over the complete AOI. At 19:10 EDT, the team arrived to UVM campus and uploaded all data collected during the day to UVM's data servers.

In total, 36 individual flights were carried out in and around the town of Plainfield for this response event, covering approximately 1500 acres of both orthoimagery and LiDAR capture over a 19-hour operational period that was split between two dates (Figure 36).

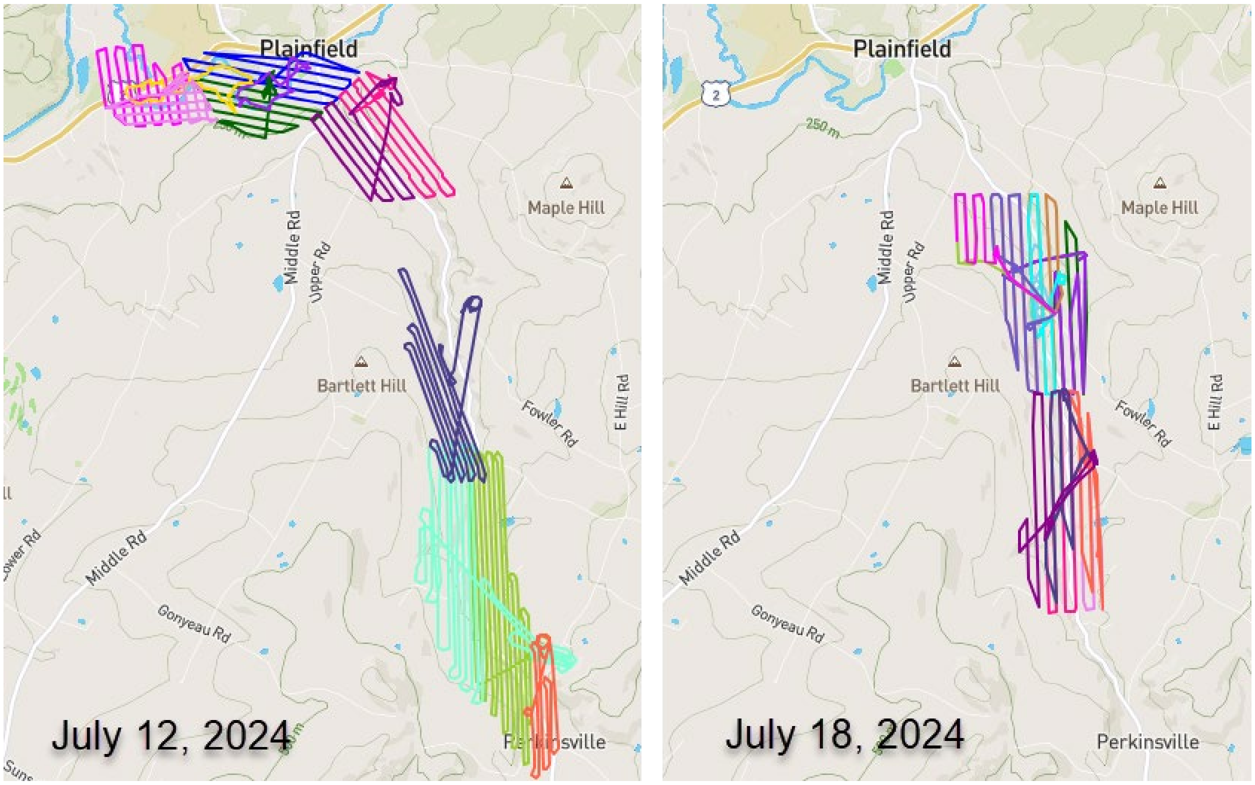


Figure 36. Flight trajectories for each date of operations in Plainfield.

1.2.4.3 Data Management, Processing and Dissemination

Following completion of the flight operations, it was critical to share the collected datasets as rapidly as possible. Once the flight crew returned to UVM, or as soon as possible the following day, the members copied the files from the field laptop and/or UAS SD cards to a UVM-hosted server system for shared access. The data dissemination practices and workflows for this response event built off of the success and lessons learned during the Great Vermont Floods of 2023.

1.2.4.3.1 Preparation

In preparation for an anticipated influx of UAS datasets in coming days and weeks, UVM and the Vermont Center for Geographic Information (VCGI) began regular communication by email and phone on July 11, 2024 and maintained daily communications through the next weeks to coordinate ingestion and sharing of UAS data products.

On July 11, UVM created an Esri AGOL Group (Figure 37) for online storage and sharing of geospatial files. A publishing account for VCGI was added to this group, so that VCGI staff would have direct access to all of the orthoimagery, 3D mesh, and LiDAR elevation products that were expected to be generated during the active response efforts. The creation of such a group and the inclusion of VCGI resolved one of the challenges identified during the flood response efforts in July 2023, as reported in ASSURE A52_A11L.UAS.68. The system implemented in July 2024 negated the requirement for UVM to email AGOL item URL links to VCGI, either in plain text or within spreadsheets. Instead, VCGI was able to extract the item links directly as a feature of their inclusion in the AGOL group.

Following generation of the group, VCGI created a Web Experience in AGOL named 'VT Flood Imagery.' This Web Experience was configured to facilitate the integration and overlay of different UAS data products, including oblique imagery, oblique video, orthoimagery, and LiDAR products.

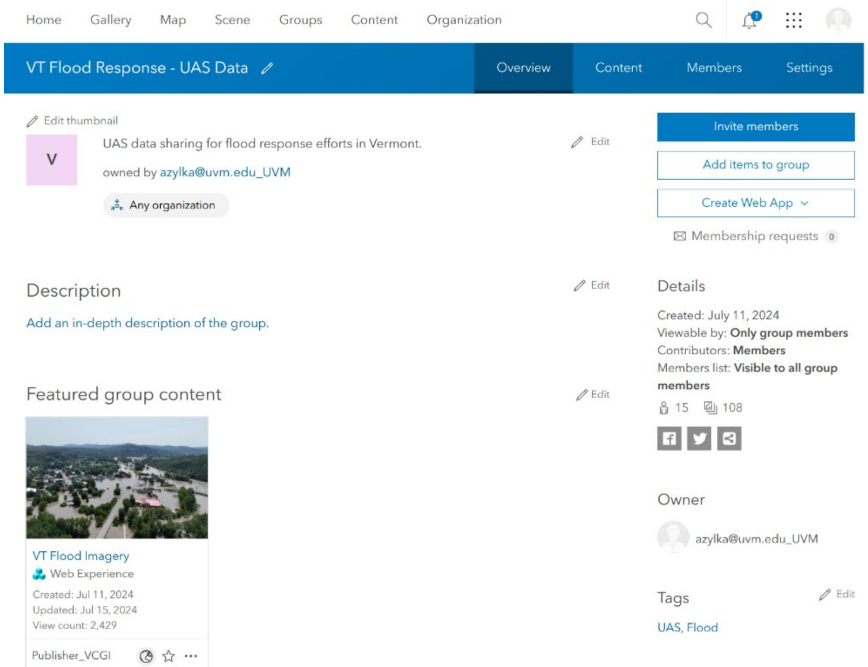


Figure 37. Esri AGOL Group for flood response UAS datasets.

1.2.4.3.2 Data Management

As discovered during flood response efforts in July 2023, as reported in ASSURE A52_A11L.UAS.68, data management was a significant priority. UVM drew on existing Standard Operating Procedures and conventions to organize more than 1 terabyte of collected and processed data, including file naming conventions and folder organization (Figure 38).

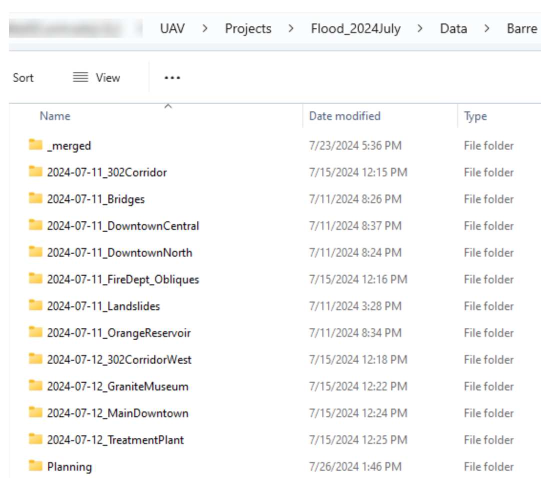
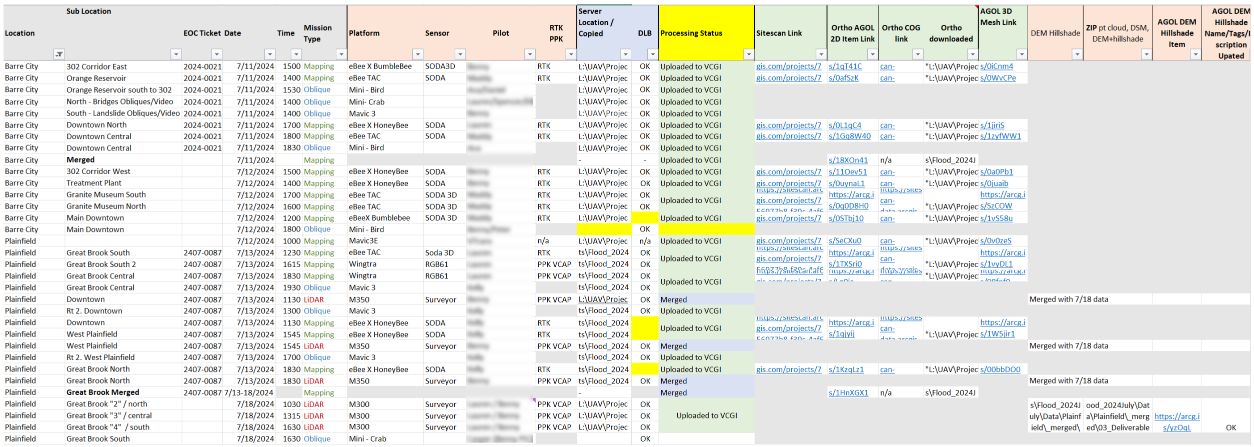


Figure 38. Data folder structure for Barre City operations.

The UVM UAS Program Lead revised a copy of the spreadsheet utilized in 2023 to track mission progress and data availability. The spreadsheet was hosted on UVM's Microsoft Sharepoint, allowing for each member of the UVM UAS Team collaboratively update and edit the status of flight operations and data processing. An excerpt from this database is presented in Figure 39, displaying the headings and categories recording through the duration of the response efforts. Generally, UAS personnel completed this database from left to right as the workflow progressed from tasked missions, to completed missions, to data processing, and data sharing. Between July 11 and July 22, 2024, this database grew to contain 96 rows corresponding to missions.

Both the Plainfield and Barre data captures required multiple day responses which required high quality data management practices such as consistent naming conventions and folder structure organization.



Location	Sub Location	EOC Ticket	Date	Time	Mission Type	Platform	Sensor	Pilot	RTK PPK	Server Location / Copied	DLB	Processing Status	Sitescan Link	Ortho AGOL 2D Item Link	Ortho COG link	Ortho downloaded	AGOL 3D Mesh Link	DEM Hillshade	ZIP pt cloud, DSM, DEM+hillshade	AGOL DEM Hillshade Item	AGOL DEM Hillshade Name/Tags/I scription Upated
Barre City	302 Corridor East	2024-0021	7/11/2024	1500	Mapping	eBee X BumbleBee	SODA3D	[illegible]	RTK	L:\UAV\Projec	OK	Uploaded to VCGI	gis.com/projects/7	s/1qT41C	can-	"L:\UAV\Projec	s/0iCnm4				
Barre City	Orange Reservoir	2024-0021	7/11/2024	1400	Mapping	eBee TAC	SODA	[illegible]	RTK	L:\UAV\Projec	OK	Uploaded to VCGI	gis.com/projects/7	s/0afSzK	can-	"L:\UAV\Projec	s/0WvCPe				
Barre City	Orange Reservoir south to 302	2024-0021	7/11/2024	1530	Oblique	Mini - Bird		[illegible]		L:\UAV\Projec	OK	Uploaded to VCGI									
Barre City	North - Bridges Obliques/Video	2024-0021	7/11/2024	1400	Oblique	Mini- Crab		[illegible]		L:\UAV\Projec	OK	Uploaded to VCGI									
Barre City	South - Landslide Obliques/Video	2024-0021	7/11/2024	1400	Oblique	Mavic 3		[illegible]		L:\UAV\Projec	OK	Uploaded to VCGI									
Barre City	Downtown North	2024-0021	7/11/2024	1700	Mapping	eBee X HoneyBee	SODA	[illegible]	RTK	L:\UAV\Projec	OK	Uploaded to VCGI	gis.com/projects/7	s/0L1qC4	can-	"L:\UAV\Projec	s/1jiriS				
Barre City	Downtown Central	2024-0021	7/11/2024	1800	Mapping	eBee TAC	SODA	[illegible]	RTK	L:\UAV\Projec	OK	Uploaded to VCGI	gis.com/projects/7	s/1Gq8W40	can-	"L:\UAV\Projec	s/1zyfWW1				
Barre City	Downtown Central	2024-0021	7/11/2024	1830	Oblique	Mini - Bird		[illegible]		L:\UAV\Projec	OK	Uploaded to VCGI									
Barre City	**Merged**		7/11/2024		Mapping					-	-	Uploaded to VCGI		s/18XOn41	n/a	s\Flood_2024J					
Barre City	302 Corridor West		7/12/2024	1500	Mapping	eBee X HoneyBee	SODA	[illegible]	RTK	L:\UAV\Projec	OK	Uploaded to VCGI	gis.com/projects/7	s/11Oev51	can-	"L:\UAV\Projec	s/0a0Pb1				
Barre City	Treatment Plant		7/12/2024	1400	Mapping	eBee X HoneyBee	SODA	[illegible]	RTK	L:\UAV\Projec	OK	Uploaded to VCGI	gis.com/projects/7	s/0uynaL1	can-	"L:\UAV\Projec	s/0juaib				
Barre City	Granite Museum South		7/12/2024	1700	Mapping	eBee TAC	SODA 3D	[illegible]	RTK	L:\UAV\Projec	OK	Uploaded to VCGI	https://sitescan.arc gis.com/projects/7	https://arcg.i s/0q0D8H0	https://sites can-	"L:\UAV\Projec	https://arcg.i s/SzCOW				
Barre City	Granite Museum North		7/12/2024	1600	Mapping	eBee TAC	SODA 3D	[illegible]	RTK	L:\UAV\Projec	OK										
Barre City	Main Downtown		7/12/2024	1200	Mapping	eBeeX Bumblebee	SODA 3D	[illegible]	RTK	L:\UAV\Projec		Uploaded to VCGI	gis.com/projects/7	s/0STbj10	can-	"L:\UAV\Projec	s/1vS58u				
Barre City	Main Downtown		7/12/2024	1800	Oblique	Mini - Bird		[illegible]			OK										
Plainfield			7/12/2024	1000	Mapping	Mavic3E		[illegible]	n/a	L:\UAV\Projec	n/a	Uploaded to VCGI	gis.com/projects/7	s/SeCXu0	can-	"L:\UAV\Projec	s/0v0zeS				
Plainfield	Great Brook South	2407-0087	7/13/2024	1230	Mapping	eBee TAC	Soda 3D	[illegible]	RTK	ts\Flood_2024	OK	Uploaded to VCGI	https://sitescan.arc gis.com/projects/7	https://arcg.i s/1TXSri0	https://sites can-	"L:\UAV\Projec	https://arcg.i s/1vyDL1				
Plainfield	Great Brook South 2	2407-0087	7/13/2024	1615	Mapping	Wingtra	RGB61	[illegible]	PPK VCAP	ts\Flood_2024	OK										
Plainfield	Great Brook Central	2407-0087	7/13/2024	1830	Mapping	Wingtra	RGB61	[illegible]	PPK VCAP	ts\Flood_2024	OK	Uploaded to VCGI	https://sitescan.arc	https://arcg.i	https://sites	"L:\UAV\Projec	https://arcg.i				
Plainfield	Great Brook Central	2407-0087	7/13/2024	1930	Oblique	Mavic 3		[illegible]		ts\Flood_2024	OK										
Plainfield	Downtown	2407-0087	7/13/2024	1130	LiDAR	M350	Surveyor	[illegible]	PPK VCAP	L:\UAV\Projec	OK	Merged						Merged with 7/18 data			
Plainfield	Rt 2. Downtown	2407-0087	7/13/2024	1300	Oblique	Mavic 3		[illegible]		ts\Flood_2024	OK	Uploaded to VCGI									
Plainfield	Downtown	2407-0087	7/13/2024	1130	Mapping	eBee X HoneyBee	SODA	[illegible]	RTK	ts\Flood_2024		Uploaded to VCGI	https://sitescan.arc gis.com/projects/7	https://arcg.i s/1qjyij	https://sites can-	"L:\UAV\Projec	https://arcg.i s/1W5jir1				
Plainfield	West Plainfield	2407-0087	7/13/2024	1545	Mapping	eBee X HoneyBee	SODA	[illegible]	RTK	ts\Flood_2024											
Plainfield	West Plainfield	2407-0087	7/13/2024	1545	LiDAR	M350	Surveyor	[illegible]	PPK VCAP	ts\Flood_2024	OK	Merged						Merged with 7/18 data			
Plainfield	Rt 2. West Plainfield	2407-0087	7/13/2024	1700	Oblique	Mavic 3		[illegible]		ts\Flood_2024	OK	Uploaded to VCGI									
Plainfield	Great Brook North	2407-0087	7/13/2024	1830	Mapping	eBee X HoneyBee	SODA	[illegible]	RTK	ts\Flood_2024		Uploaded to VCGI	gis.com/projects/7	s/1KzqLz1	can-	"L:\UAV\Projec	s/00bbDO0				
Plainfield	Great Brook North	2407-0087	7/13/2024	1830	LiDAR	M350	Surveyor	[illegible]	PPK VCAP	ts\Flood_2024	OK	Merged						Merged with 7/18 data			
Plainfield	**Great Brook Merged**	2407-0087	7/13-18/2024		Mapping					-		Merged		s/1HnXGX1	n/a	s\Flood_2024J					
Plainfield	Great Brook "2" / north		7/18/2024	1030	LiDAR	M300	Surveyor	[illegible]	PPK VCAP	L:\UAV\Projec	OK	Uploaded to VCGI						s\Flood_2024J uly\Data\Plainf ield_merged\	ood_2024July\Dat a\Plainfield_merg ed\03_Deliverable	https://arcg.i s/yzOqL	OK
Plainfield	Great Brook "3" / central		7/18/2024	1315	LiDAR	M300	Surveyor	[illegible]	PPK VCAP	L:\UAV\Projec	OK										
Plainfield	Great Brook "4" / south		7/18/2024	1630	LiDAR	M300	Surveyor	[illegible]	PPK VCAP	L:\UAV\Projec	OK										
Plainfield	Great Brook South		7/18/2024	1630	Oblique	Mini - Crab		[illegible]			OK										

Figure 39. Data management spreadsheet utilized to track mission tasking, data collection, data processing, and data sharing status. Flights filtered to display missions in Barre City and Plainfield.

Flight logs from all UAS platforms used during the response were synced to the DroneLogBook log management platform within 48 hours following flight operations to ensure compliance with UVM's internal policies about flight log retention.

1.2.4.3.3 Oblique Imagery and Video

The oblique images and videos captured during the response efforts were reviewed and organized for sharing purposes. A selection of JPG-format images and MP4-format video files were zipped to an archive and uploaded to a Google Forms link (Figure 40) that VCGI created to facilitate rapid sharing of these basic data products. From the ingest through Google Drive, the files were added to VCGI's Amazon Web Services storage buckets before being displayed as selectable points in a publicly accessible web mapping application. The points representing the images and videos could be displayed in the approximate position they were recorded due to the file metadata including the GPS coordinates of their capture (EXIF metadata within the JPG images and supporting SRT subtitle files aligned with the MP4 files). A screenshot of the web application is presented in Figure 41.

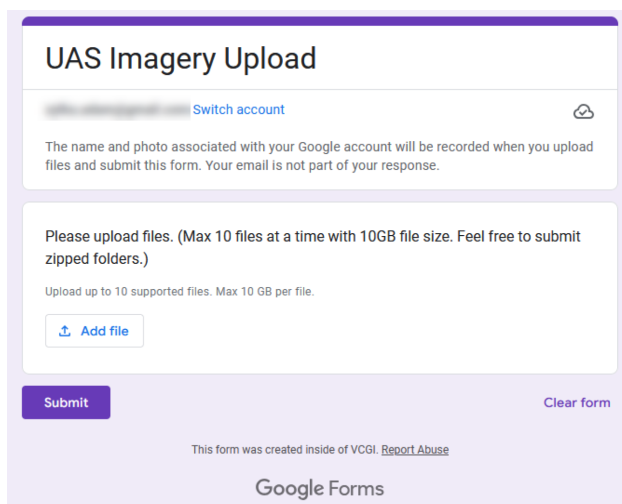


Figure 40. Google Form created by VCGI for oblique image and video upload.

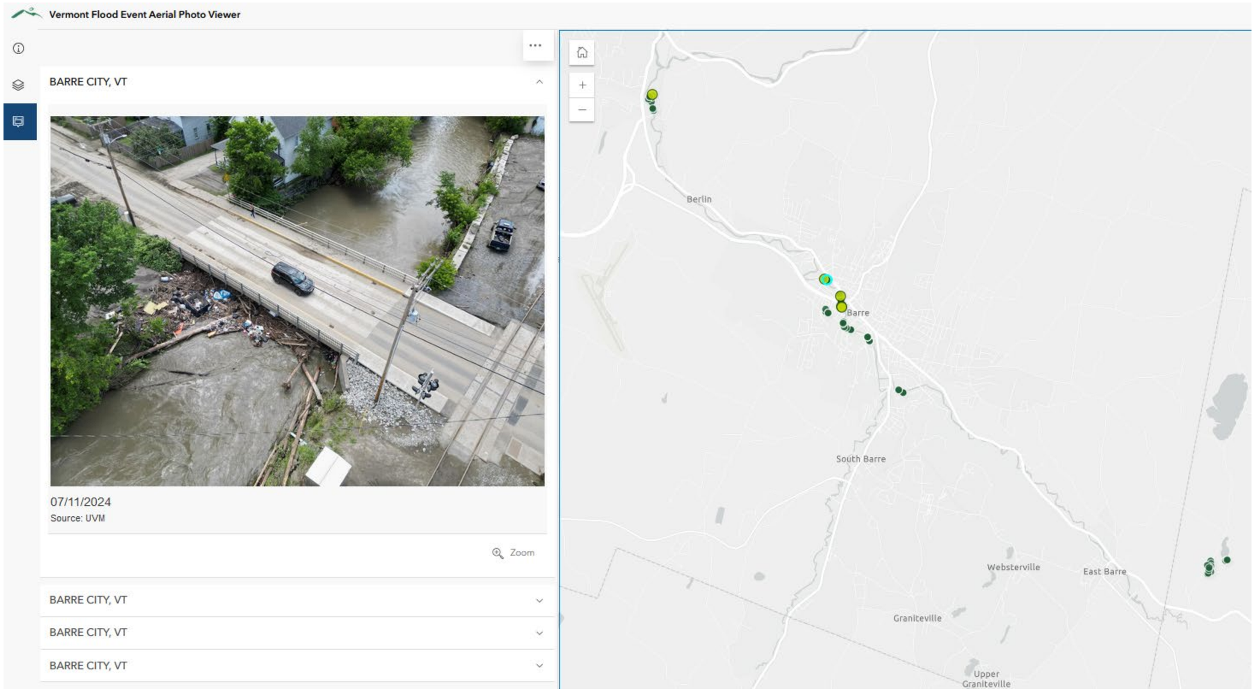


Figure 41. AGOL Web Experience with integrated oblique UAS imagery (green dots) and video (yellow dots) in Barre City.

VCGI developed a custom workflow to automate the ingestion, transformation, and integration of these data to the web experience (Figure 42). FME software package was used to organize and transform the uploaded images (Figure 43) so that the images could:

- Displayed on a map according to the coordinates at which they were captured
- Renamed according to the town in which they were collected
- Transformed to public-facing Amazon Web Service bucket for storage and indexing

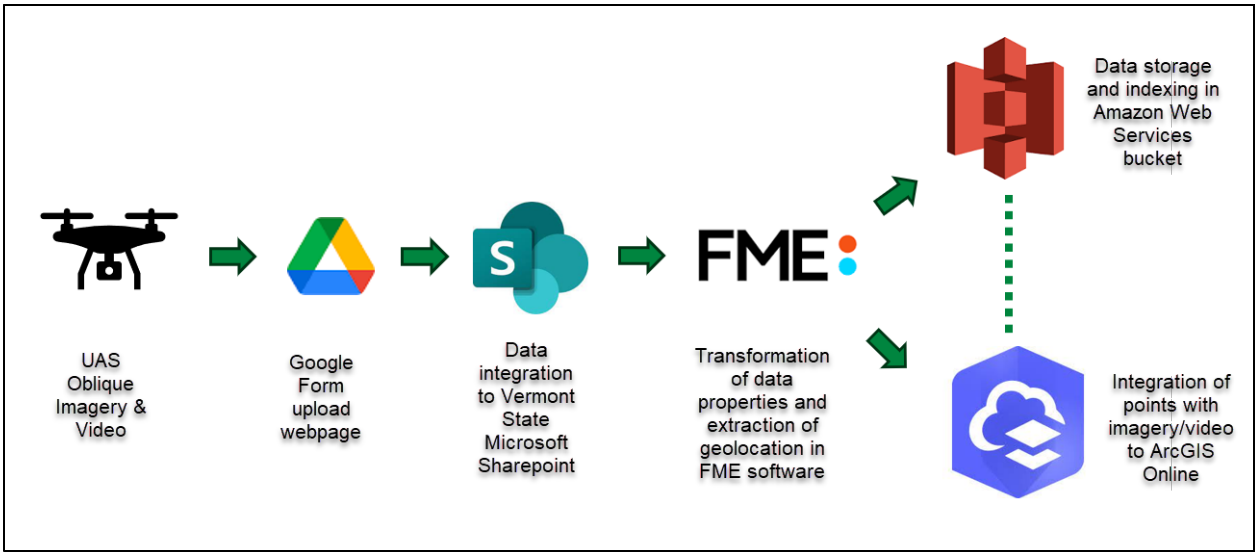


Figure 42. VCGI workflow for integration of UAS oblique imagery and video to AGOL Web Experience.

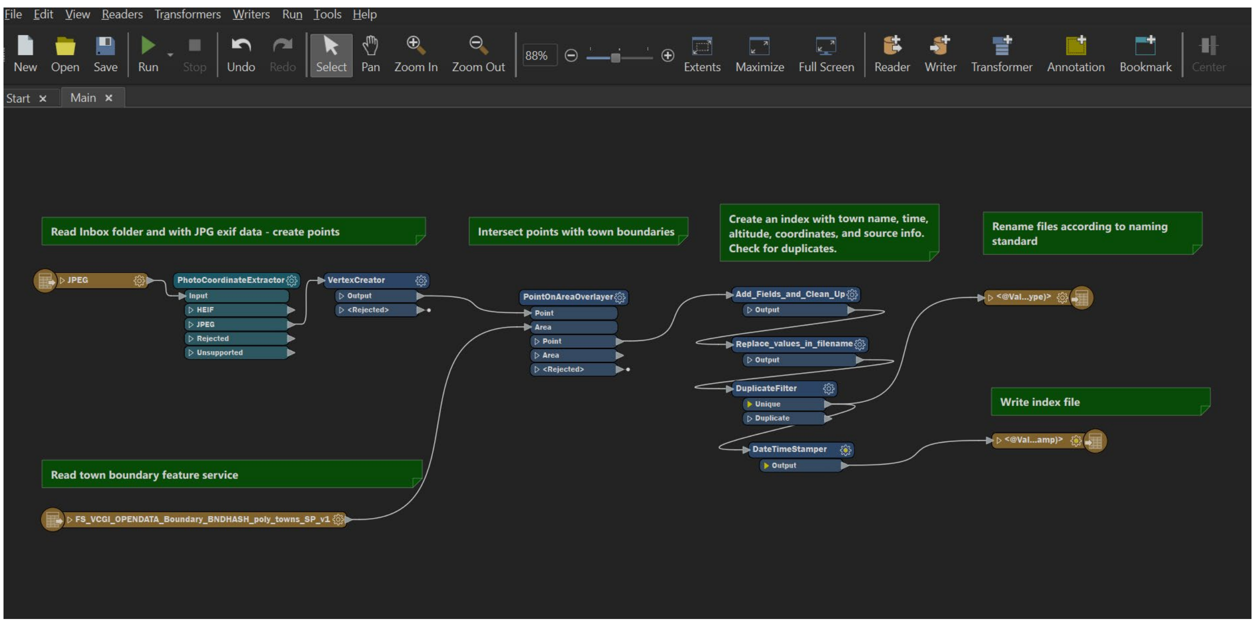


Figure 43. Detailed overview of data transformation workflow in FME software, including creatio.

1.2.4.3.4 Orthoimagery

The secondary data dissemination process for this event was to generate orthoimagery from the imagery captured during the mapping missions. Images from mapping missions were imported into Esri SiteScan, a cloud-based application for photogrammetric processing. Following lessons learned from flood response in 2023, it was determined that this cloud-based solution had a number of advantages as opposed to localized processing using software such as Esri Drone2Map or Pix4Dmapper, such as the ability to process many projects at once, reduce local storage needs, directly share products to AGOL, and simplify the processing workflow. UVM worked directly with Esri's Disaster Response Program to improve the utility of the settings within SiteScan for the response, including enabling the ability to publish orthoimagery and 3D mesh data layers directly to specific AGOL groups, such as the group set up for these response efforts.

For the flights that used the eBee X platform, image coordinates were corrected during flight using RTK and were uploaded directly into SiteScan. For images that were collected using the WingtraOne Gen II platform, a PPK workflow was executed in WingtraPilot software in order to improve the accuracy of location data for each image. This process used the VCAP Continually Operating Reference Station (CORS) located in nearby Montpelier, Vermont. Once the images had been PPK'd, they were uploaded onto SiteScan with the eBee X images, totaling approximately 68 gigabytes (GB) of input imagery for mapping in Barre and 133GB of data for Plainfield. As a result of the large areas mapped, SiteScan was unable to accommodate more than 5000 images in a single processing project and therefore each mission set was processed individually to be merged together once complete (Figure 44).

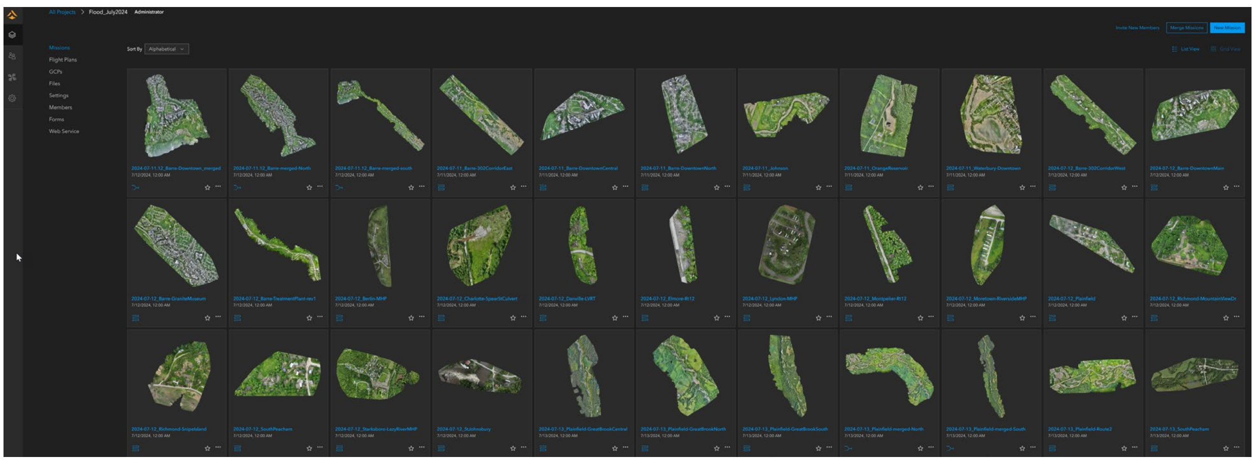


Figure 44. SiteScan projects for missions carried out between July 11 and July 13, 2024.

Once images were loaded, the processing could begin online and continue even as the device or workstation was closed, allowing for background processing to occur as the UAS Team continued with other operations. The product of this processing included a 2D orthomosaic as well as a 3D integrated mesh (Figure 45), which were shared directly to the AGOL group from SiteScan's cloud storage. Additionally, a link to the Cloud-Optimized GeoTiff (COG) of the orthomosaic was shared to VCGI, so that they could import the COG to an Amazon Web Services bucket for storage and public access. These data were typically available via AGOL in 4-6 hours after upload to SiteScan.

Figure 45. Output 2D and 3D products in Plainfield, VT generated through processing in Esri SiteScan software.

VCGI proceeded to integrate the 2D and 3D products into the AGOL Web Experience as displayed in Figure 46 and Figure 47. Additionally, VCGI developed a comparison feature to display post-flood UAS orthoimagery next to pre-storm aerial maps (Figure 48).

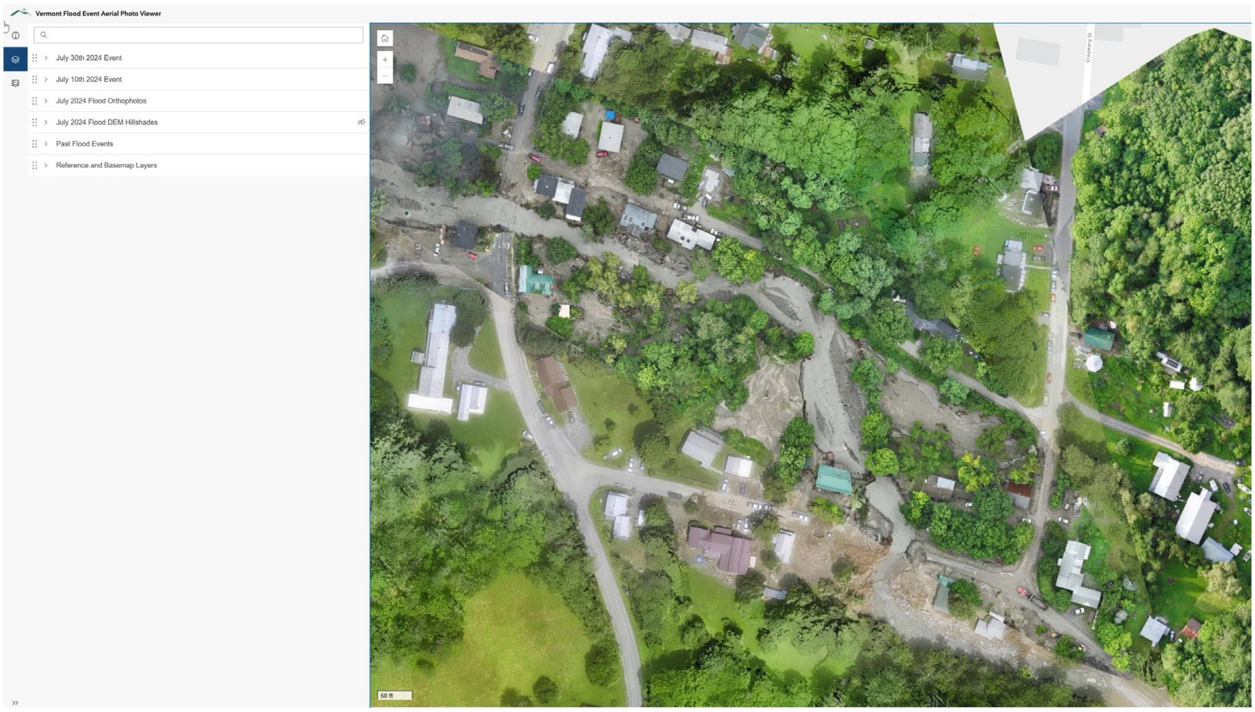


Figure 46. Orthoimagery over Plainfield, VT displayed in AGOL Web Experience.

Figure 47. Integrated 3D mesh over Plainfield, VT displayed in AGOL Web Experience, including integration with aerial images.

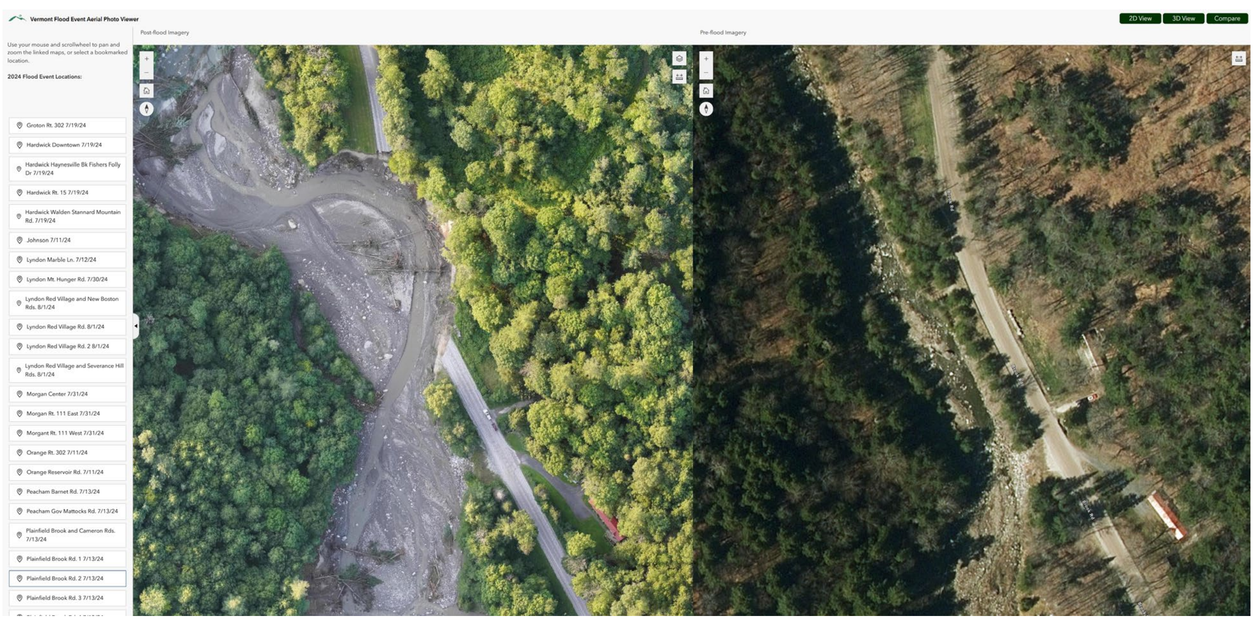


Figure 48. Orthoimagery comparison feature in AGOL Web Experience. Post-storm UAS orthoimagery to left and pre-storm aerial imagery to right.

1.2.4.3.5 LiDAR

The processing of LiDAR captured in Plainfield began with PPK corrections of the flight trajectory using Applanix POSPac software and data from nearby VCAP CORS station. A point cloud was generated using YellowScan CloudStation software and the corrected trajectory. Utilizing

LAStools software, the point cloud was classified to differentiate between ground and above ground features, and then used to generate a digital elevation model (DEM) representing bare earth, which was of highest interest to stakeholders. For public viewing, the DEM was imported into ArcGIS Pro, a hillshade was generated, shared to AGOL and ingested by VCGI for the web app viewer. The UAS LiDAR derived data products allow for 3D visualization of the scene and for highly detailed measurements of distance, height, area, and volume. Due to the high accuracy of these products (often in the range of 1-2 inch in horizontal and vertical planes), comparisons can be carried out to determine topographical changes that may have resulted from the flooding event.

On July 17, 2024, the UVM UAS Program Lead received a call from a Geotechnical Engineer in the VTrans Highway Division, requesting LiDAR products of a landslide along a state highway to the west of downtown Plainfield. It was determined that UVM captured data over this location on July 12 and were able to deliver data products of the landslide to the engineering teams for analysis in Computer Aided Design (CAD) software. Specifically, it was determined that the DEM of the landslide site, containing only areas classified as ground features was of primary interest for this analysis. The format in which these were delivered could be LAS, LAZ, or POS to allow the engineers to create a terrain surface in their CAD software. The UVM UAS Team also collected LiDAR over this location during flood response in July 2023 and provided those files to the geotechnical engineers for time-series comparisons (Figure 49). It was determined that the toe of the landslide had moved more than 10 meters as a result of the July 2024 storms (Figure 50).

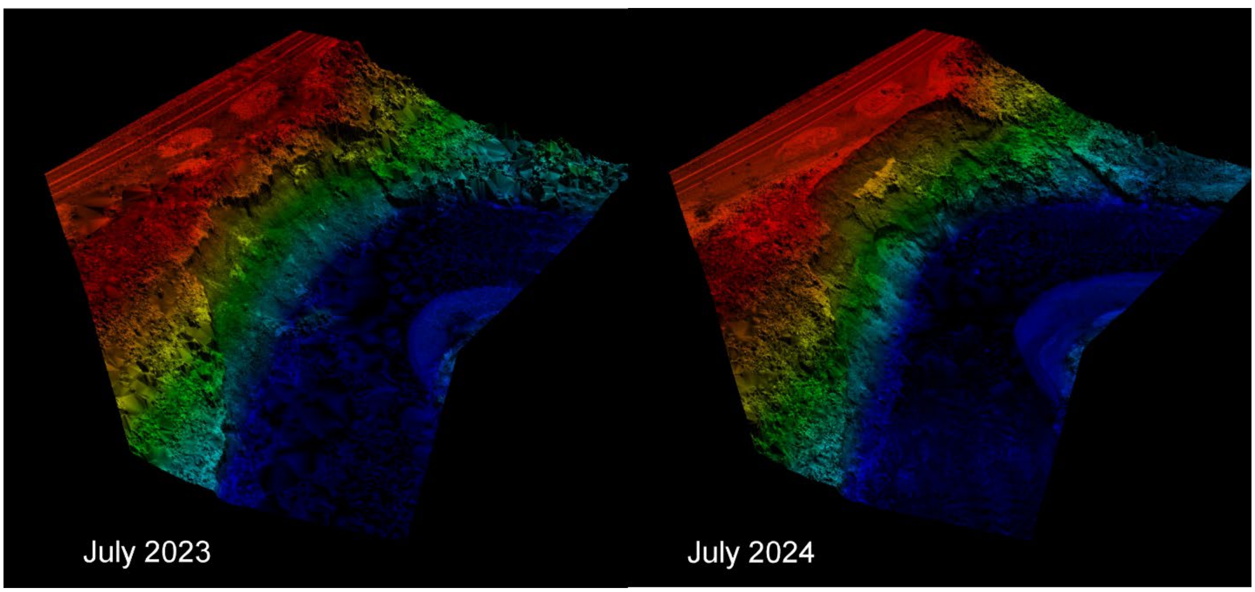


Figure 49. DEMs of Plainfield landslide in 2023 and 2024.

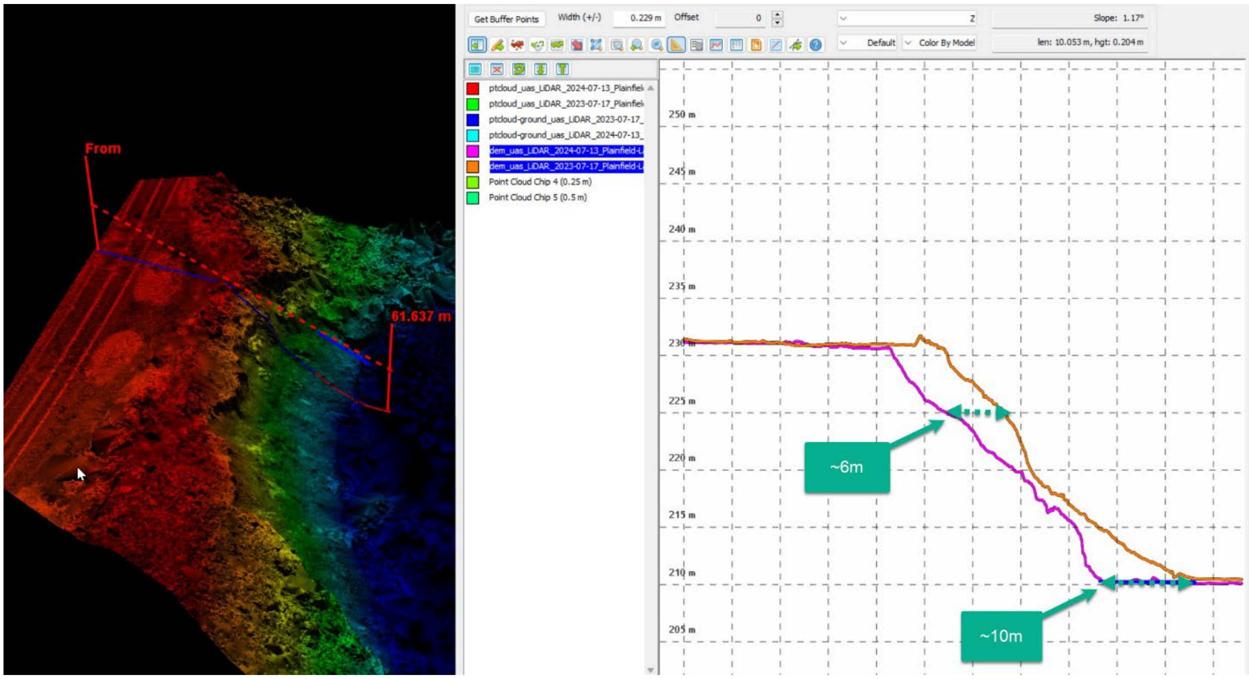


Figure 50. Elevation profile view of Plainfield landslide in July 2023 (orange) and July 2024 (pink) showing significant changes resulting from the July 2024 storms.

1.2.5 Flood Response Event Follow-Up Activities, If Applicable

Once data was disseminated to VCGI and made publicly available, stakeholders accessed the data for local and state decision making. Through the public publishing of the captured UAS datasets, the Federal Emergency Management Agency (FEMA) Region 1 Geospatial office were able to ingest and share the data across divisions across the agency. Data uses include:

- Educating the public about the extent of damage caused by the flooding, with high resolution images of damaged areas. The Town of Plainfield used the UAS data to support outreach during hosted seminars with community members and potential funders for recovery, as well as the Vermont SEOC Team as a briefing for damage recovery.
- Comparisons to past imagery and elevation data to facilitate discussions about post-flood recovery and reconstruction.
- Documentation of damage and changes to river flow for infrastructure reconstruction, which includes new channels that may have been created. The Town of Plainfield was introduced to several new channels created by the Great Brook which took out the Mill Street Bridge on July 13, 2024. The Road Commissioner used the data to prioritize infrastructure repairs for the short term.
- Search and rescue of lost property, including vehicles and other large objects.
- Supporting requests for Public Assistance Recovery funds from FEMA.
- The City of Barre used the imagery for grant appropriation requests in order to request funding for recovery and resiliency.
- State Hazard Mitigation Teams used the data to identify locations that would most likely remain uninhabited due to potential hazardous materials and the likelihood of future flooding events.

- Imagery was used as teaching materials for other first responders in the area.
- Orthoimagery was integrated into FEMA's SARCOP tool to be used by first responders and FEMA personnel for future responses.

The collected UAS-LiDAR data provided reliable information used to analyze landslides. This required the expertise of state geologists and engineers to assess the stability of identified slides and develop mitigation strategies for future movements. The VTrans Geotechnical Engineers requested an additional UAS-LiDAR collection from UVM in November, 2024 in order to assess the changes to the large Plainfield landslide over 4 months. Topographic differencing was also explored to quantify the changes in rivers and the impact to communities in the river corridors (Figure 51).

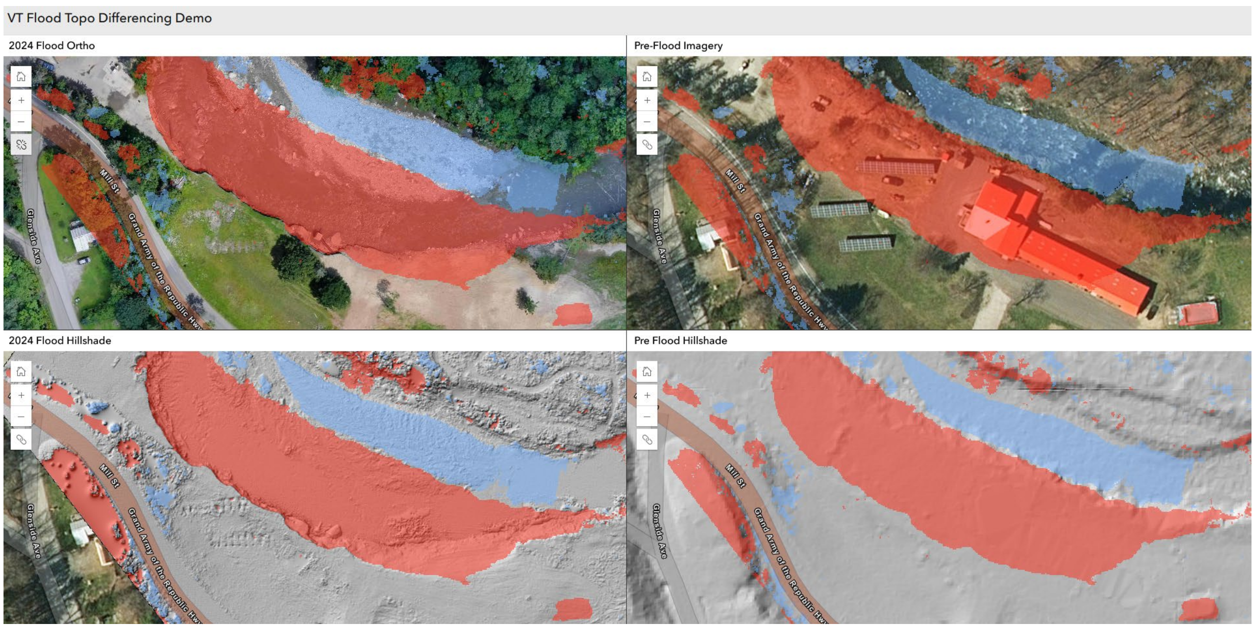


Figure 51. Topographic differencing showing erosion of riverbank (red) captured in UAS-LiDAR.

Following the completion of flights in Barre and Plainfield, the UAS Team continued operations in additional areas as requested to capture more data of damage from the flooding. Between July 1 and October 15, 2024, VCGI's 2024 Flood Event Aerial Photo Viewer received 43,434 requests with an average of 409 requests per day (Figure 52, Figure 81). Access to these data for this flood event had numerous daily peaks between July 11 and 16, with over 7,000 visits on July 15, 2024.

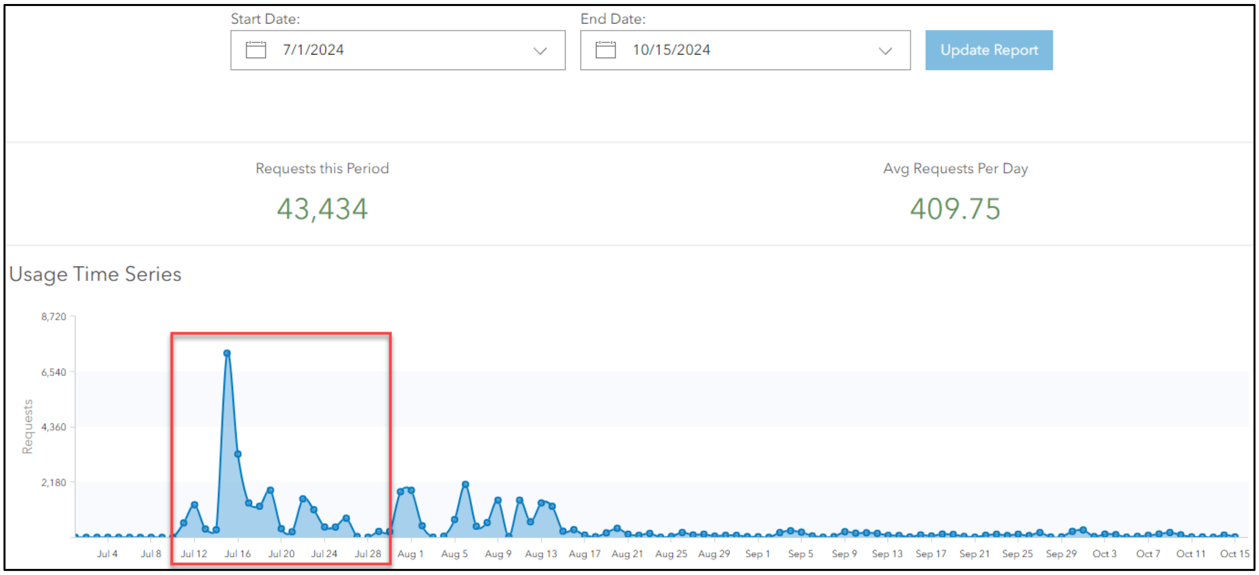


Figure 52. Usage statistics of VCGI's Flood Event Web Application, with July 11, 2024 flood event usage highlighted in red box.

1.2.6 Lessons Learned from the Flood Response Event, Including Responses to Research Questions

1.2.6.1 Flood Response Event Key Findings:

- SGI request process
  - The FAA's SGI procedure can be less responsive and rapid than expected, particularly during times in which a series of disasters are impacting areas across the country and when SOSC is unable to have multiple staff available to process requests.
  - The way in which requests are prioritized for SGI approved by the SOSC is opaque to the requesting organization, particularly for flood response efforts when capturing high-water marks in UAS imagery can make a significant impact towards expediting the distribution of recovery funding.
  - Best practices and standardized training for submitting SGI requests would benefit both the requesting organizations and the SOSC to improve efficiency.
    - What organizations count as public safety?
    - What materials do organizations supporting public safety agencies need to provide to be processed under SGI process?
  - Developing flight area using a polygon allows for more specific requests for waiver/authorization via SGI. UVM used Google Earth to draw a polygon covering the requested flight area and document coordinates of the vertices, which was cumbersome to convert from geospatial file to list of text coordinates.
- Communication and tasking
  - Communication and collaboration between local/regional organizations that are familiar with the capabilities and capacities of different UAS teams is extremely valuable.
    - VTrans UAS Program Manager knew that UVM UAS had OOP capabilities and sufficient crew members to carry out mapping over cities and towns, such as Barre and Plainfield.

    - The UVM team was contacted directly by local agencies and first responders who were familiar with their capabilities, but there was confusion of who they should be directed to for official EOC taskings.
    - Having community members or personnel that are familiar with locations of interest support UAS strike teams navigate and communicate.
        - During the response in Plainfield, the UVM Team communicated with Plainfield Emergency Management contacts prior to the response to ask for recommendations for good staging areas for flights. With recommendations for staging areas and liaisons, navigating Plainfield became much more efficient, especially with road closures throughout the area.
        - In Barre, since areas of interest were the same as previous responses, the UVM Team was already familiar and knew of successful staging areas which made traveling through Barre more efficient.
- Data management and processing
    - UVM utilized a spreadsheet to keep track of every flight and dataset collected during the response, allowing for detailed tracking of data collection, processing, and sharing status.
    - A cloud-based photogrammetry solution for orthomosaic and integrated 3D mesh generation more efficient and scalable compared to using software running on local workstations. Solving challenges related to sharing these data products directly to AGOL allowed for streamlined sharing and integration of layers to public-facing portals.
    - Local base stations, such as CORS stations, during this response were running as normal in contrast to the previous response, where several CORS stations were downed due to flooding damage. These local base stations allowed for accurate positioning for data and images which also speeds up the process for orthomosaic regeneration. With the VT CORS system up, RTK was readily available for imagery and meant no need to PPK images during processing.
- Data dissemination and application
    - In contrast to the previous flood response data dissemination strategy of having VCGI creating their own AGOL group to digest data through, UVM instead created their own and shared access to VCGI. This allowed for an easier time for sharing datasets directly to the group, instead of having to upload and send datasets via file transfers to VCGI which was done during the previous response. With the UVM AGOL group, UVM was able to process data through ESRI Site Scan cloud processing for orthomosaics and 3D meshes and instantly upload them to the cloud. VCGI then was able to grab those datasets from the cloud much quicker, without having to download them, and integrate them into web apps for public access and FEMA SARCOP integration.
    - UAS-LiDAR
        - Topological data provided base plans and cross sections and identified critical features for future engineering designs.
        - Cross sections were used for slope stability modeling for identifying areas of instability and to develop mitigation strategies for infrastructure.
        - LiDAR models from July 2024 were compared to past data captures (UAS-LiDAR and aerial LiDAR) to understand changes in the slopes.

        - UAS-LiDAR removed the need to send personnel to survey the landslide by hand. This allowed data capture of inaccessible and dangerous locations by foot and provided high resolution and high accuracy data of the slope.
        - UAS-LiDAR allowed for rapid data capture which may have taken days or weeks without the use of UAS. This allowed for quick decision making for temporary measures to allow residents to evacuate or find other means of navigating around the landslide. Data later was then used to make longer-term solutions before the winter season.

1.2.6.2 Flood Response Functional Exercise Recommendations:

- SGI request process
    - Recommend the FAA conduct review of SOSC operational capacity to identify improvements in the SGI request and approval process to avoid delays, including but not limited to staffing levels during periods of wide-scale disasters.
    - Develop documentation and/or training for first responders to optimize efficiency of SGI requests including clear guidance on how types of emergencies are prioritized.
    - Enhance geospatial integration for definition of flight areas as part of SGI request. Allow method for requesting organizations to submit KML or SHP file containing polygon of flight area, rather than text input of polygon vertices.
- Communication and tasking
    - Establish database, on state, regional, or federal level, of organizations capable of providing specific types of UAS support for disaster response (i.e. OOP, livestream, mapping, data management, etc.)
- Data management and processing
    - Consider developing standards for data naming and file/folder structure.
    - Consider development of standardized template to be used by response organizations operating UAS to track tasking, data collection, data processing, and data sharing status.
    - Recommend, when available, a cloud-based photogrammetry solution to allow scalable large-scale UAS mapping deployments for orthomosaic and integrated 3D mesh.
- Data dissemination and application
    - Develop standard procedures for integration of UAS datasets to emergency response scenarios, ideally at state level (within a SEOC) but also at regional or local levels when applicable.
        - Identify organizations who will be activated to manage and share UAS generated datasets.
        - Develop relationships between state and regional geospatial agencies and UAS response teams capable of providing and sharing datasets.
        - Develop and provide training to such geospatial professionals on best practices for ingesting UAS data and making publicly available.
    - Improve outreach across local and state groups to increase awareness of UAS data availability and use cases, including supporting requests for recovery funding.

1.2.6.3 Flood Response Functional Exercise Informed Research Question(s):

1. How effective are the policies, procedures and guidelines as used in the exercises?

- The SGI request process to allow for airspace authorization took more than 6 hours for approvals, resulting in inability to capture aerial imagery during high-water marks. Efficiency and transparent of SGI procedures and capacity of FAA SOSC can be improved.
- There was confusion on EOC direct contacts especially between local organizations that needed help and the EOC. UVM ended up becoming the messenger, telling organizations who to contact to get official EOC tickers which is inefficient. There is still a level of uncertainty, especially from smaller towns and cities as to who to contact when there are specific needs that need to be met during a response. State-wide policies for integration of UAS into response plans must be developed.

2. When a disaster or emergency happens, what should future coordination with federal governmental agencies look like when UAS are fully integrated into the NAS?
    - Federally hosted database of organizational capabilities within an impacted region would allow for rapid identification of resources to respond to specific regional and local emergency events.
    - Federally maintained database containing certifications of UAS PICs could allow for enhanced permissions for PICs meeting specific thresholds.
    - Communication may be streamlined to a designated airboss, either at state or federal level, to improve efficiency of tasking, especially in complex or constrained airspace.
3. What are the considerations of disaster and emergency UAS Traffic Management (UTM) during manned/unmanned joint operations?
    - Standards for prioritization of UAS operations must be created to allow for emergency operations to take precedent over other UAS applications. Furthermore, standards for the prioritization of emergency UAS tasks should be evaluated.
4. What are the barriers to entry for local, state and federal organizations employing UAS technology for disaster and emergency response and recovery?
    - Funds and support for purchasing UAS platforms.
    - Familiarity with UAS data applications beyond ‘real-time video stream’
        - Dedicated data manager to coordinate UAS response and mapping operations.
    - Availability of training for first responders and decision makers, especially in more remote locations.
    - Tariffs and limits on UAS manufacturers and availability.
        - NDAA-compliance limits UAS platform choice and exponentially increases the price of equipment.
5. What enabling technologies or advancements would aid future disaster preparedness and emergency response?
    - Development of standard tool to allow for rapid upload of oblique imagery and videos as soon as possible following flight.
    - On-board processing capabilities on UAS to generate orthoimagery products and/or 3D models in near-real time during flight.

- Enhanced 5G connectivity to UAS systems to relay livestream, imagery, and video to data processing pipelines during flight.

6. What data should be gathered to support lessons learned and process improvements?
    - Records of organization's workflow from collecting data to stakeholders getting a hold of that data. This is so that other UAS programs can learn from each other on how to effectively and efficiently get their data into the hands of decision makers.
    - A list of types of sensors, platforms, and software packages for specific scenarios so that UAS programs can have specific checklists for specific mission types. Newer UAS programs sometimes have difficulties with defining what platforms, sensors, and software are best to be used for certain situations.
    - Development of state, regional, and/or federal database of capable UAS organizations that can be relied upon for emergency response scenarios.

1.2.6.4 Flood Response Functional Exercise Lessons Learned Summary:

UAS allows quick, easy data capture for hard-to-reach locations during a disaster response while keeping responders safe from dangerous environments. The events of Hurricane Beryl in Vermont in July 2024, showed how powerful the use of UAS can be in capturing data for decision-making, situational awareness, and damage assessments. With the experience of the previous flood in 2023, the UVM UAS Team could quickly deploy and navigate the correct channels to obtain tasking from the activated Vermont SEOC and disseminate data products with enhanced efficiency and at great speeds.

The UVM UAS Team employed similar workflows from the previous flooding response events and enhanced the efficiency of data processing and dissemination by using already made and trained workflows for rapid and high-quality data. The integration of in-house workflows for data processing and dissemination also allowed UVM to work within their software ecosystem and the cloud, which allowed for faster creation and sharing of data products to state agencies and the public. Using ESRI's SiteScan was integral to this workflow, as it allowed for parallel processing of dozens of projects simultaneously. Combined with the experience of UVM in data dissemination using AGOL, and the close relationship with VCGI, sharing orthoimagery to decision-makers was possible within a matter of hours following tasking of flight operations.

Consistent and efficient data management also was integral to UVM's success. The UVM UAS Team kept detailed records of every single flight on a spreadsheet to track tasking requests, data collection progress, and processing and sharing status. These details helped keep track of all 182 flights during this response. Naming conventions and folder structures on UVM's servers were also kept consistent, which made navigating through hundreds of datasets much easier, especially when datasets were worked on by multiple personnel.

There are still lessons to be learned during this response which include creating a more streamlined process of communication between the EOC and the organizations that need help for a disaster response. Confusion of who to contact and how to contact was prevalent as the UVM UAS Team was contacted directly for requests on multiple occasions and had to instead redirect to the correct

EOC channels for official requests and taskings. Although this happened quickly during this response, there needs to be better knowledge and training for town and city officials to learn how to properly request help.

With the growing number of UAS programs within the state, there also needs to be a solid understanding of UAS capabilities between each organization. In this way, decision-makers can effectively task each team based on their capabilities for more efficient and higher-quality data capture.

1.3 07/30/2024, Flood and Landslide Response Event, Northeast Kingdom Vermont, Conducted by the Univ. of Vermont (UVM)

The State of Vermont was impacted by flooding, landslides, road washouts and catastrophic damage following severe storms from July 29-31, 2024. The initial rainstorm beginning in the late hours of July 29th dropped between 6-9 inches of rain causing flash flooding across the state, with the worst of the storm focused in Vermont's Northeast Kingdom (NEK). During the state's third devastating flooding incident in just over a year, countless road closures were put in place, swift-water rescue teams were activated to reach stranded residents, and a State of Emergency was activated in Vermont. UVM's UAS Team began sUAS flight operations to support response and recovery efforts on July 30, 2024 and operations continued through August 7, 2024. In total, around 40 individual sUAS flights were carried out in support of the flooding event. On September 26, 2024, the July 29-31 event officially received a Major Disaster Declaration from President Biden.

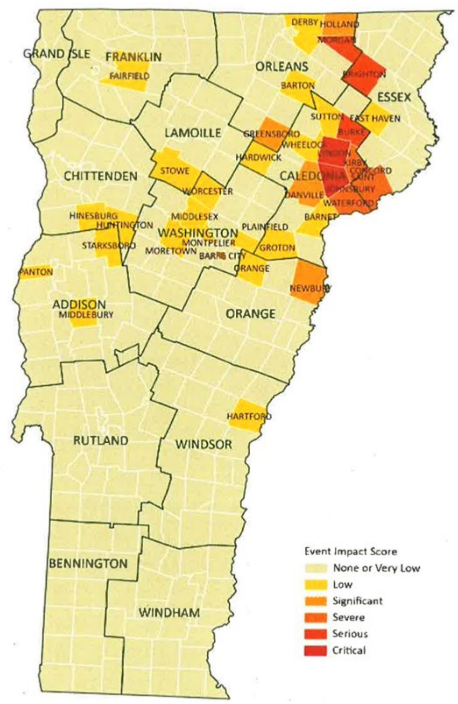


Figure 53. The hardest hit towns from the July 29-31 flooding event are displayed in red. Both St. Johnsbury and Lyndon have the most intense event impact score of "critical" based on a number of factors such as road closures, damage reports and Local Liaison feedback.

This functional exercise presents a set of sUAS flight operations in the towns of St. Johnsbury and Lyndon, with the purpose of documenting water levels, road washouts, landslides, infrastructure damage and other impacts from the flooding event. These operations took place in some of the most severely impacted regions in the state (Figure 53) and were particularly illustrative of the variety of challenges and lessons learned during the overall flood response.

1.3.1 Objectives of the Flood Response Functional Exercise

The purpose of these operations were to acquire UAS imagery and mapping data to visualize the flooding extent and damage in hard-hit regions, support rapid geospatial damage assessments and additional analysis, provide documentation to support a request for a federal disaster declaration and to aid in future flood resiliency research and planning. This real-world response also served as a way to evaluate the UVM UAS Team's procedures, capabilities, limitations, processing, and dissemination activities while capturing lessons learned and best practices for future operations.

1.3.2 Planning for and Logistics of the Flood Response Functional Exercise

Initial planning for these operations began the morning of July 30, as Vermonters began to realize the severity of the impacts of the flooding that began the previous night. The UVM SAL UAS Team Lead contacted the EOC to let them know the team could be available for UAS operations, as well as notified the VTrans Rail and Aviation Director of the team's availability. The Director of VCGI, who has been invaluable in assisting with dissemination of UAS data during past flooding events, was also contacted and began making calls to determine where UAS support was most needed. At 12:41 EDT, the UAS Program Lead sent a message in Slack, the lab's internal communication software system, to alert the UAS Team to standby for potential deployment. A channel had been previously created for the flooding that occurred earlier in the month, offering a dedicated space to continue messaging and planning for this newer flooding event.

Despite delays and challenges in relaying official EOC tasking for UVM's UAS operations, internal and external coordination were carried out to identify priority locations for UAS response. The UAS Team first gained insight into which areas were experiencing intense rainfall through the National Weather Service rainfall map for Northeast Vermont, which revealed heavy rain in Caledonia and Essex counties (Figure 54). The team also viewed the National Water Prediction Service for the Passumpsic River which flows through the previously identified counties; it was found that the river reached moderate flood stage in the early morning of July 30 (Figure 55). The combination of this information allowed the UAS Program Lead to determine that sUAS operations should be executed in St. Johnsbury, Vermont as soon as possible on July 30 to attempt to capture impacts of the flash flooding in the urban area. Contacts at VCGI and VTrans relayed a list of potential locations to capture UAS data based on the observed by VTrans personnel on the ground, including landslides adjacent to a VTrans office and several sections of roads and bridges that had been severely damaged around St. Johnsbury and into the town of Lyndon. Beyond the immediate impacts across St. Johnsbury, it was determined that Lyndon would be the next priority location to map due to the immense damage to roads, which washed away buildings and left some residents stranded, with pedestrian and ATV traffic the only way to navigate around impacted properties. Details of the impacts to rural Lyndon continued to be relayed on July 31 and August 1. Throughout the following hours and over the next several days, planning meetings occurred for

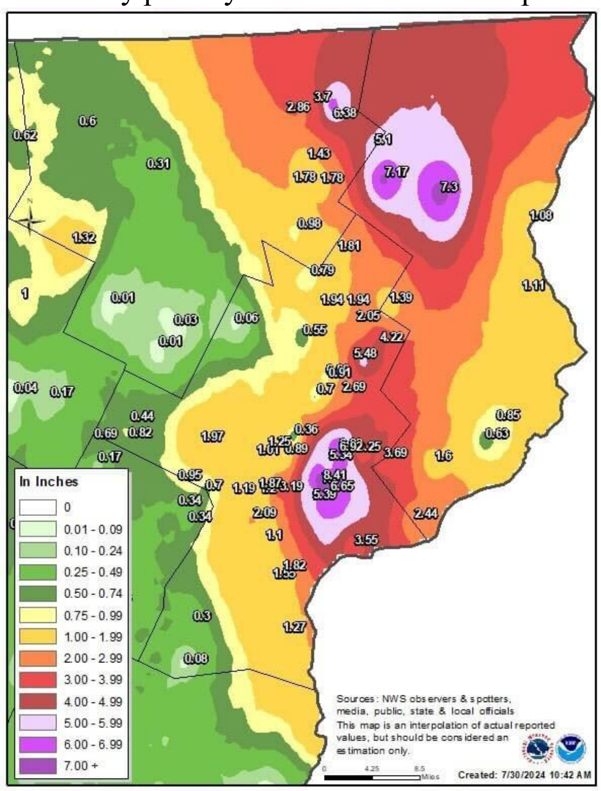


Figure 54 . Northeast Vermont total storm rainfall ending July 30, 2024.

the UAS team to organize response teams, assign mission priorities, allocate resources and prepare equipment for anticipated operations.

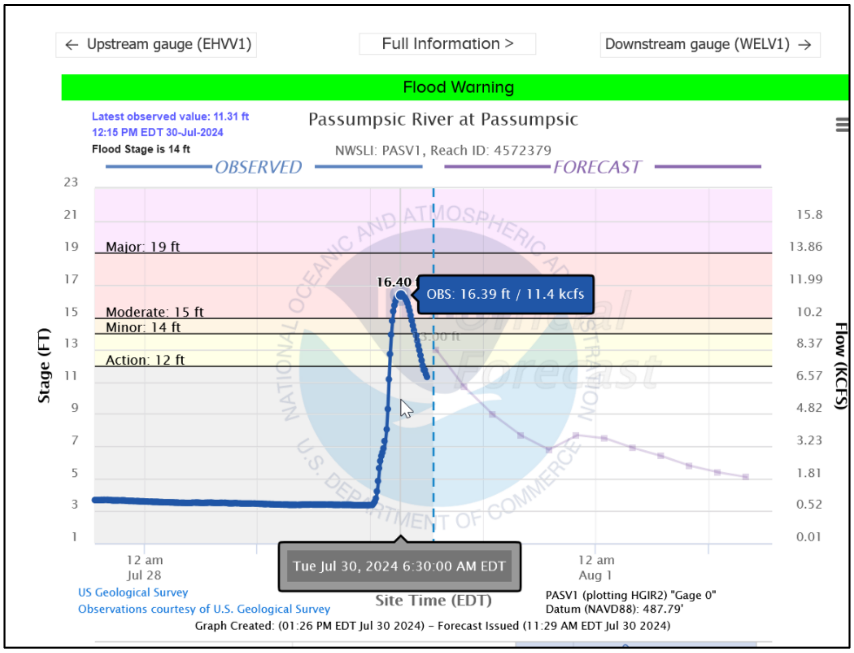


Figure 55. Water level of Passumpsic River, which hit moderate flood stage the early hours of July 30.

The UAS crews assigned to each mission began with a review of the anticipated flight area and surrounding airspace. Both St. Johnsbury and Lyndon are located in Class G airspace, which eliminated the need for additional airspace authorizations under Part 107.

Due to limited planning time before deployment to St. Johnsbury on July 30, a variety of UAS were packed in order to allow for flexibility once arriving at the locations of interest. The chosen platforms and sensors included a DJI Matrice 350 RTK with RGB and LiDAR capabilities, which would allow for collection of mapping imagery and elevation data from confined areas. An AgEagle eBee X with RGB capabilities was brought to enable efficient, true-color mapping flights over urban areas if needed, due to its efficient battery life and OOP-compliance. Finally, a DJI Mini 3 Pro, a smaller multirotor platform, was selected due to its portability and ability for rapid deployment and capture of oblique aerial imagery and video. Due to uncertainty about the precise location of impacted areas, it was decided that flight plans could be generated as needed during field deployment. To facilitate this process, offline maps were cached ahead of time in case there was unreliable internet connection.

On July 31 at approximately 16:30 EDT, a contact from the Vermont Agency of Natural Resources (ANR) called the UAS Team Lead to request UAS data along Red Village Road in Lyndon. The UAS Team carried out a thorough briefing meeting that night and planned to deploy on the morning of August 1. The UAS Program Lead compiled a series of rough AOIs and their associated priorities in Lyndon and surrounding areas (Figure 56). The capture of oblique photos and videos or small mapping missions of minor road washouts was set as a secondary priority, as road crews had been quick to repair those sites and further analysis, or documentation was no longer critical. The larger, time-intensive mapping missions would instead be focused on river change and human/community impacts, as this documentation would be vital in recovery efforts. Based on the objectives of collecting oblique photos and videos, EO mapping imagery, and elevation data, the Lyndon Team packed the relevant platforms and sensors. This included a DJI Matrice 300 RTK with the P1 24mm EO sensor and YellowScan Surveyor LiDAR sensor for mapping operations, and a DJI Mini 3 Pro for oblique photo and video collection. It was anticipated that the flooding damage may result in limited launch and land areas, so a fixed-wing platform was not ideal due to their inability to launch and land from confined spaces. Since there were estimated areas of interest, the RPIC decided to develop flight plans prior to deployment. These flight plans will be further discussed in the execution section.

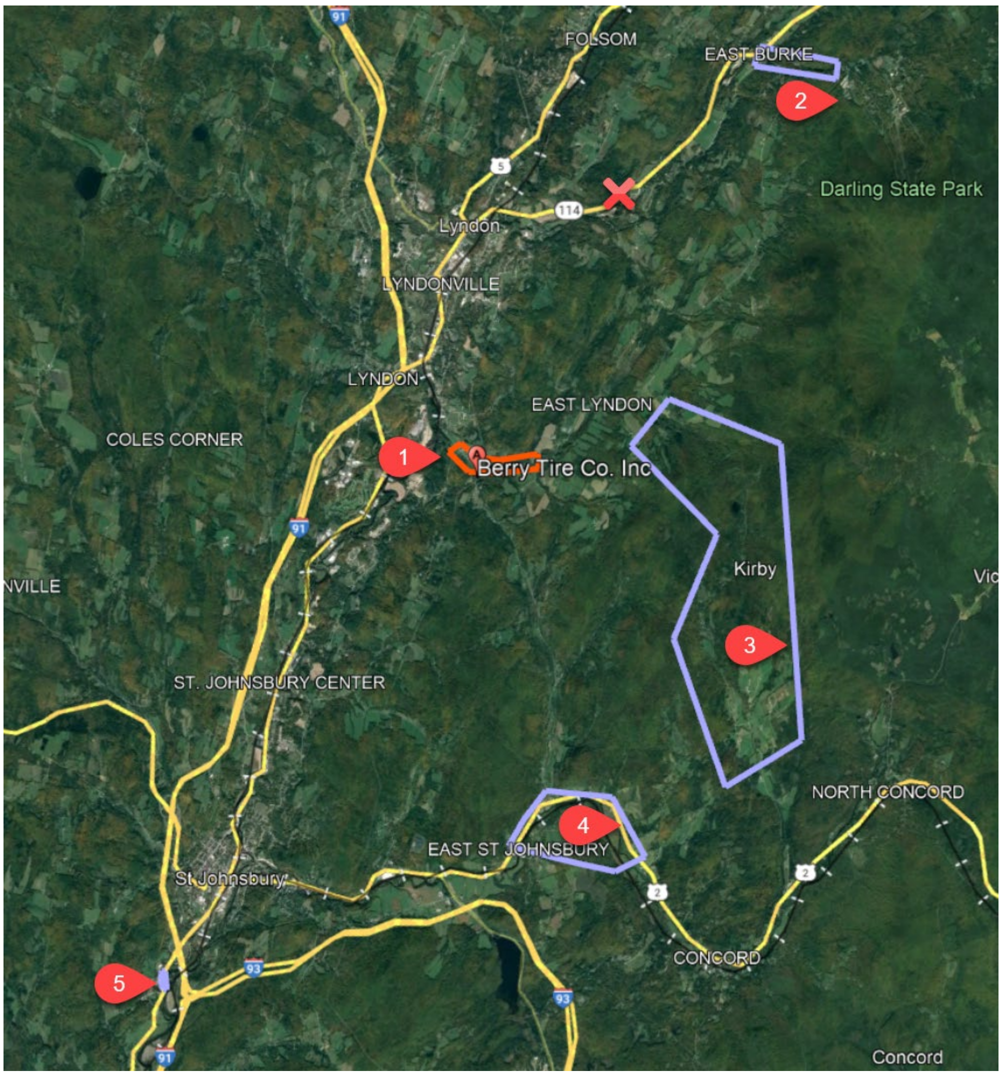


Figure 56. Approximate AOIs developed by UAS Program Lead for August 1 operations in and around Lyndon. The highest priority, marked with the red "1" pinpoint, is Red Village Road. The red "X" represents a known road closure.

Before and during deployment to St. Johnsbury or Lyndon, UAS crews utilized New England 511, which provides real time traffic updates, to verify road conditions and adjusted their planned driving route accordingly. In some instances, the teams were required to pass road closure signs and establish communication with other responders on the scene to ensure the area was safe for parking and UAS deployment.

1.3.3 Flood Response Functional Exercise Execution

The UAS operations in St. Johnsbury took place on July 30, 2024 and UAS operations in Lyndon took place on August 1, 2024.

1.3.3.1 St Johnsbury

At 13:37 EDT on July 30, the UAS Program Lead began packing equipment for operations in St. Johnsbury. Due to staff availability and scheduling, the location of flood impacts, and reduced risk threats associated with operating in Class G airspace, the Program Lead determined that he would individually constitute a UAS strike team as RPIC.

By 15:41 EDT, the Program Lead was on route to St. Johnsbury for UAS operations. During this transit period, additional staff were reviewing the list of potential sites provided to narrow down priorities based on damage severity and feasibility of UAS operations. While en route, the UAS Program Lead and UAS Team members conducted a coordination call at 16:50 EDT to discuss tasking priorities and access routes to avoid the many road closures.

1.3.3.1.1 East St. Johnsbury – Route 2

The Program Lead arrived in St. Johnsbury just before 17:00 EDT. Two initial flights with the DJI Mini 3 Pro for oblique imagery and video capture were carried out at washout and small landslide locations along U.S. Route 2 in East St. Johnsbury between 17:06 EDT and 17:19 EDT. Oblique imagery sets in JPG format, along with video clips in MP4 format were captured during these operations.

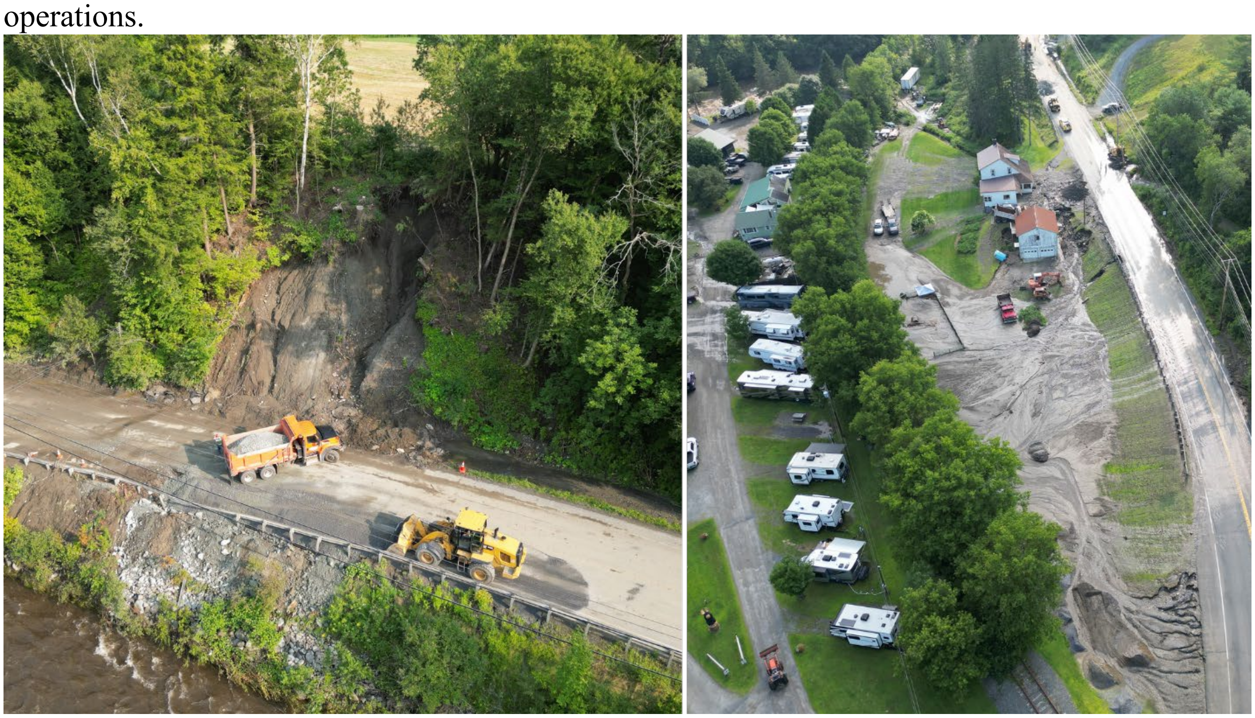


Figure 57. UAS imagery captured along Route 2 in East St. Johnsbury displaying impacts of landslide (left) and washout (right).

1.3.3.1.2 South St. Johnsbury – Route 5 Landslides

At 17:27 EDT, the Program Lead arrived at the State facilities hosting offices for Vermont State Police Troop A St. Johnsbury and the VTrans District 7 maintenance garage, co-located along State Route 5 as it runs approximately 100 feet in elevation above the Passumpsic River. Multiple sections of the riverbank experienced localized landslides, including a slide that resulted in the loss of the eastern lane of the roadway. Road crews were active on this site to stabilize and remove the significant debris. The RPIC carried out an initial flight with the DJI Mini 3 Pro to capture aerial imagery and video for documentation of the damage. During the flight, the RPIC noted a secondary landslide that had occurred along the riverbank and made the determination that carrying out a mapping mission to further document the two adjacent slides could be of value for assessing slope stability. After completing the flight, the RPIC then prepared the DJI M350 and P1 EO sensor according to the organization's pre-flight checklists with the intent of capturing mapping-grade imagery of the slides. Based on the information gained during the previous flight, the RPIC was able to rapidly generate an automated mapping flight plan for the UAS that would capture both areas of interest. The RPIC completed a 9-minute mapping mission capturing high accuracy nadir EO imagery. The state VRS network was utilized for RTK corrections to enhance spatial accuracy of the images.

Figure 58. UAS imagery of landslides impacting and/or threatening State Route 5.

1.3.3.1.3 Lyndon – Route 114 Washout

With four flights completed, the RPIC continued north to the next sets of potentially impacted regions, arriving near the intersection of Route 114 and Mt. Hunger Rd by way of Interstate 91 near 18:00 EDT. This intersection was unpassable due to the destruction of the bridge along Rt 114. As had become standard practice, the RPIC prepared the DJI Mini 3 Pro for an initial flight in order to aerially scout the damage and to collect oblique imagery and video. The RPIC was able to show a curious local resident some of the live video feed from the UAS controller.

Figure 59. UAS imagery showing significant damage to homes (left) and bridge along Route 114 (right).

Upon the completion of this 5-minute flight, a reporter from a local news outlet arrived on the site with a small consumer DJI sUAS. In this instance, the RPIC was able to discuss with this reporter about their UAS activity and the two parties were able to come to a verbal understanding of each other's objectives. The UVM RPIC used the time during which the media member was flying their UAS to prepare the DJI M350 platform for imagery and LiDAR collection. Of note was that this media personnel was not wearing a high-visibility vest denoting them as a sUAS RPIC, nor did they appear to complete a pre-flight checklist prior to launch. This person stated that they were flying their 'personal drone' for this media capture and therefore it was not clear if they were operating under either the Part 107 or hobbyist regulatory frameworks. The ability for both parties to meet physically was an unlikely, yet useful, coincidence. Had either party arrived to conduct their UAS operations from the north of the damaged bridge, it would have been very difficult to visually identify and coordinate with the other UAS operator.

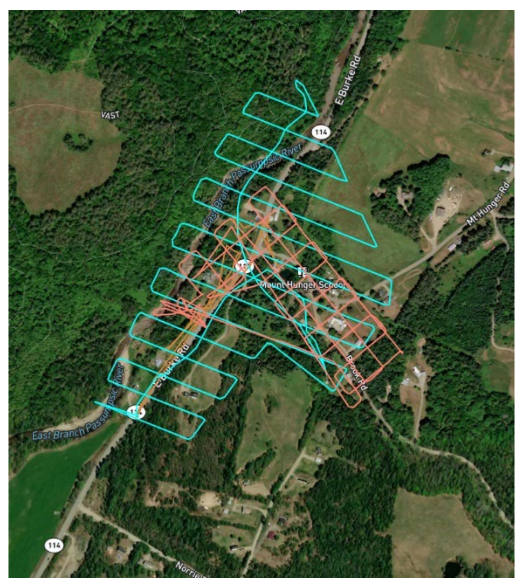


Figure 60. Overlay of flight paths carried out by UVM RPIC including oblique image capture (orange), LiDAR (pink), and orthoimagery mapping (blue).

Upon completion of the media's UAS flight, the UVM RPIC carried out subsequent orthoimagery collection and LiDAR capture missions over the area of damage observed during their previous flight. The RPIC was limited by VLOS in their ability to continue to follow the damage upstream, particularly during the LiDAR mission carried out at a lower altitude of 230 feet AGL. The RPIC transferred all collected data to a rugged laptop and validated the extent of the collection.

1.3.3.1.4 St. Johnsbury Center

The RPIC made their way south along Route 5 from Lyndon towards St. Johnsbury to determine if there were other impacted areas that might benefit from UAS data capture. At approximately 20:15 EDT, the RPIC encountered a road closure on Route 5 in St. Johnsbury Center. The neighborhood adjacent to this closure and the Passumpsic River appeared to be covered in mud, silt, and water. Making the decision that data capture of these impacts would be valuable, the RPIC again prepared the M350 UAS and P1 sensor for an automated mapping mission, beginning at 20:20 EDT. Civil twilight in this location was between approximately 20:14 EDT and 20:48 EDT and therefore the RPIC enabled the use of the integrated strobe light atop the UAS platform, with this white flashing anti-collision lighting being designed for visibility exceeding 3 Statute Miles. The RPIC also relied on an additional pre-flight checklist designed to provide risk assessment and mitigation for the additional potential hazards of operating after sunset. During the mapping mission, the RPIC noted that the live feed from the sensor was fairly dark on the controller screen but was unsure if this was related to the reduction in controller screen brightness carried out prior to flight. Following completion of the automated mapping mission, the RPIC attempted to capture sets of oblique imagery of the impacted area using the same sensor and manual flight control. Upon landing the UAS, the RPIC made the realization that the camera settings should have been adjusted to better compensate for the low light conditions, including a reduction in shutter speed and increase of the ISO. Following the completion of this mission, the RPIC returned home to begin to organize, process, and disseminate the datasets captured.

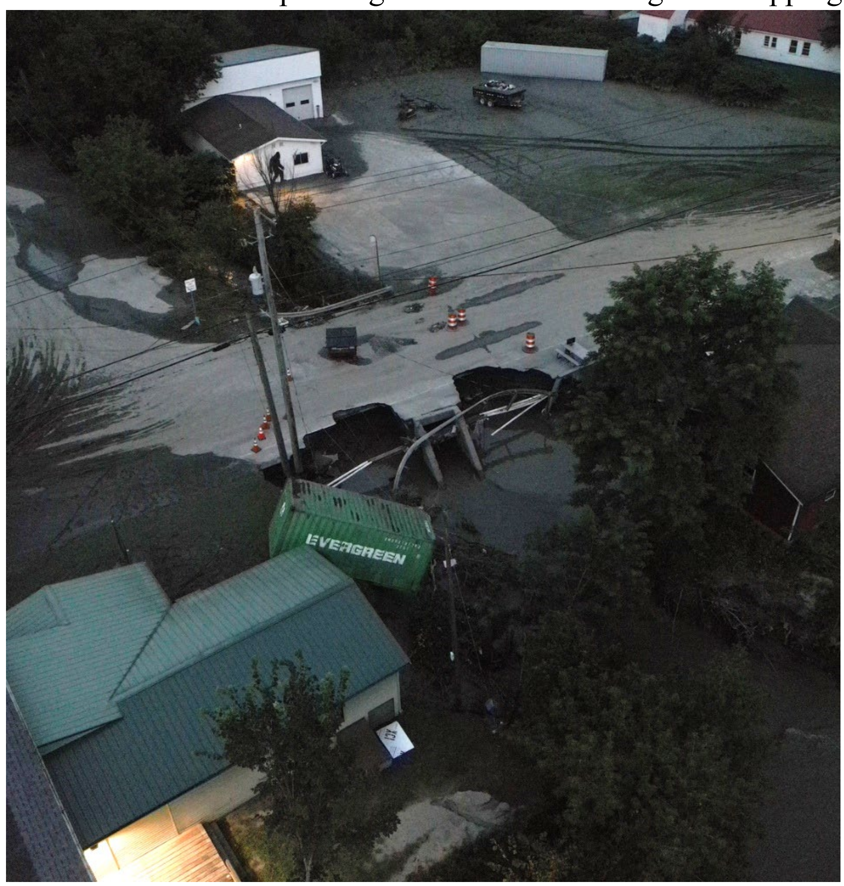


Figure 61. UAS imagery displaying bridge damage along Route 5 in St. Johnsbury Center.

1.3.3.2 Lyndon

Following severe flooding in Lyndon, the VTrans UAS team was deployed to assess transportation infrastructure damage around the town. The Governor of Vermont had created a special task force to assess stream and river debris at the request of constituents and road foreman who were concerned about continued impacts from these large debris piles. When the VTrans UAS Program Manager unexpectedly crossed paths with one of the task force members in a state office building, the pair were able to consider the value of UAS for this mission. VTrans initiated UAS deployment along Red Village Road, tasking the team with mapping the affected areas to identifying debris that could impede recovery efforts, and documenting additional damage to transportation infrastructure.

Upon arrival on scene the morning of August 1, access to Red Village Road was one of the primary difficulties that the VTrans RPIC faced. With parts of the road damaged or impassable due to washouts from the flooding, it was necessary to find alternative routes. During the operation, the RPIC happened upon a friend with an ATV, which proved crucial in navigating the challenging terrain and getting to areas with better line of sight, significantly improving the efficiency of the mission. Without this type of local connection that is possible in a rural region of a small state, it is unlikely that mapping this corridor would have been possible under Part 107 regulations requiring the RPIC to maintain VLOS. Neither the UVM UAS Team nor the VTrans RPIC were familiar with the requirements to request a beyond visual line of sight (BVLOS) waiver/ Certificates of Waiver or Authorization (COA) through the SGI process.

The RPIC conducted three separate UAS flights over Red Village Road with a DJI Mavic 3 Enterprise, each targeting a different section of the damage (Figure 63). The first flight covered the western portion of the road, while the second focused on the middle stretch, accessible only by the ATV. The final flight extended farther east, covering the remainder of the road and completing the mapping mission. Due to the challenging terrain and the need for flexibility in the field, the UAS flights were conducted manually. The RPIC relied on visual landmarks to guide the flights along the water and ensure adequate overlap between images. This manual approach, though more labor-intensive during flight than pre-planned automated flights, allowed for greater adaptability. In one instance, the damage extended beyond the initial assessment area, requiring the RPIC to quickly adjust the flight route and collect additional data.

Figure 62 . VTrans RPIC preparing for flight operations.

Throughout the operation, the RPIC employed an automatic two-second interval between image captures to ensure thorough coverage of the river corridors and damaged infrastructure. In most instances, there were multiple flights paths covering an area for greater overlap between images for processing, but in one instance there was only a single flight line (Figure 64). The real-time collection of data enabled a comprehensive view of the scale of damage in areas that had not yet been seen by ground teams. The data was not entirely collected with RTK and did not have PPK capabilities, however, meaning there could still be a benefit of more precise and accurate collections moving forward.

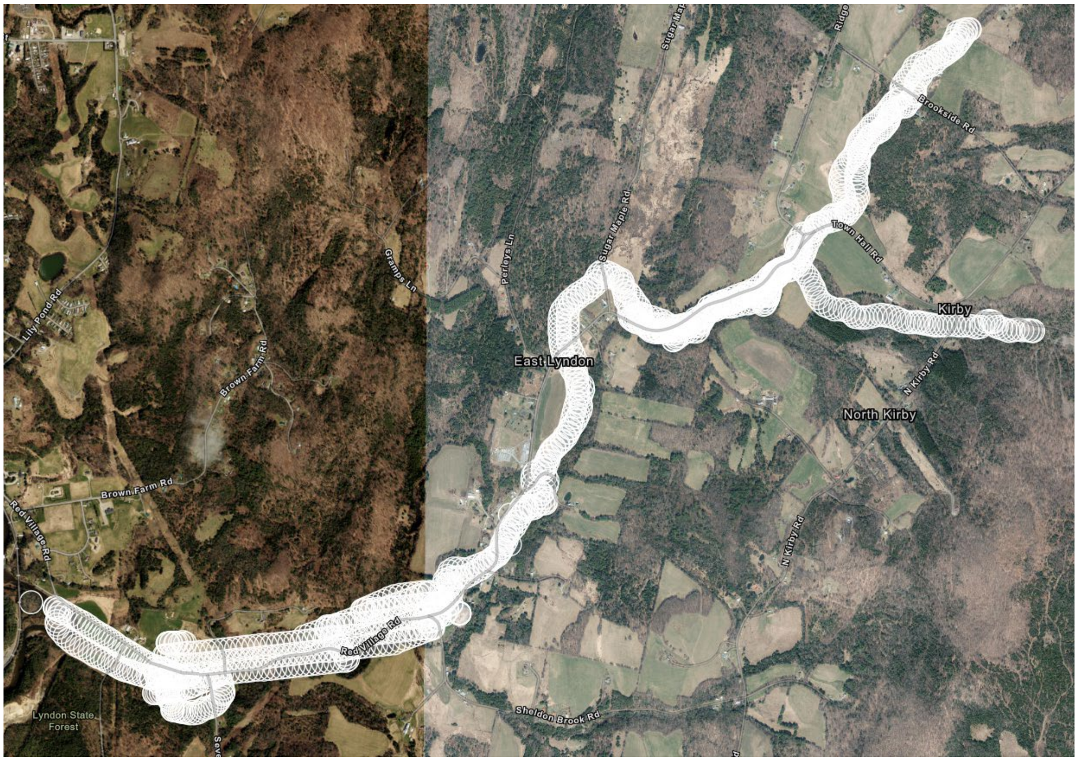


Figure 63. Full area covered by VTrans mapping. White circles represent image footprints.

Figure 64. Detailed view of image footprints. Some portions of the corridor have multiple passes, while another area only has a singular flight pass.

Coordination with other teams in the area, including USAR and UVM, was critical. Although not initially planned, these multiple UAS Teams were deployed to the same region, making it necessary to communicate about airspace and avoid conflicts. The RPIC was able to complete the flights without direct interference, although it was noted that having some central coordination tools to be aware of other operations would have been helpful.

The morning of August 1, the UVM UAS Team was also tasked with operations in Lyndon and surrounding towns. The UAS crew packed up the prepared equipment and left the SAL at around 9:45 EDT. Based on the priority list, they first deployed to Red Village Road in Lyndon, where they were able to navigate around road closures by notifying traffic officers of their intention to collect mapping data of flooding impacts. The area had significant sediment and debris and the road was busy with vehicles from homeowners and other responders. The UAS crew was able to park in a somewhat open grassy area close to the start of the washed-out road. This staging area was chosen for adequate launch and land space away from vehicle or foot traffic as well as its proximity to the AOI (Figure 65).

Figure 65. Staging area for UVM Team shown in the red circle. The road washouts are further east on Red Village Road.

Upon arrival, the RPIC sent an update in Slack to keep the rest of the team up-to-date and aware of the Lyndon crew's whereabouts and operations; a practice that has been established for the safety of the crew while conducting UAS flights, particularly during emergency response. The crew began setting up for operations, following a pre-existing mission checklist in the Fulcrum app. This included steps such as verifying airspace, identifying risks and hazards, assigning roles, confirming usage of hi-vis vests, verifying that radios were operating properly and ensuring the launch and land area was clear of obstructions. The team also set up the Starlink portable wifi network, which would enable internet connection during operations if needed. The RPIC contacted the UAS program director of VTrans and the USAR team, who were both known to be in the area, notifying them of planned flight operations. It was confirmed that the crews were far enough away from each other that there would be no overlap in flight areas and operations could continue as planned without need for further airspace partitioning or deconfliction.

To scope out the extent of the damage and confirm the AOI before mapping operations, one of the UVM UAS pilots confirmed airworthiness of the DJI Mini 3 Pro and manually launched the platform at approximately 12:21 EDT. They gained situational awareness of the scene, highlighted which areas were of priority to capture based on damage level and captured oblique photos and videos as evidence of the flood extent and impacts to the area (Figure 66).

Figure 66. Aerial views of Red Village Road at 12:23 EDT on August 1, 2024. Parts of the road have been destroyed due to the flooding, and the remaining sections and nearby property is covered in sediment and debris piles.

Once the DJI Mini 3 Pro was landed, it was determined that the LiDAR flights would begin next. There was an incredible amount of stream movement and erosion that would benefit from LiDAR collection, making it a higher priority. Additionally, VTrans had already collected a corridor of imagery, making an additional imagery collection lower priority. Based on the scoping flight, it was confirmed that the pre-generated flight plan for LiDAR collection covered an area of intense damage around the water and nearby properties, aligning with the objectives of the mission. Although the goal was to cover an entire strip from New Boston Road to Sheldon Brook Road (Figure 67), the area was split into two separate flight blocks with the intention of launching from separate areas for better line of sight with the platform.

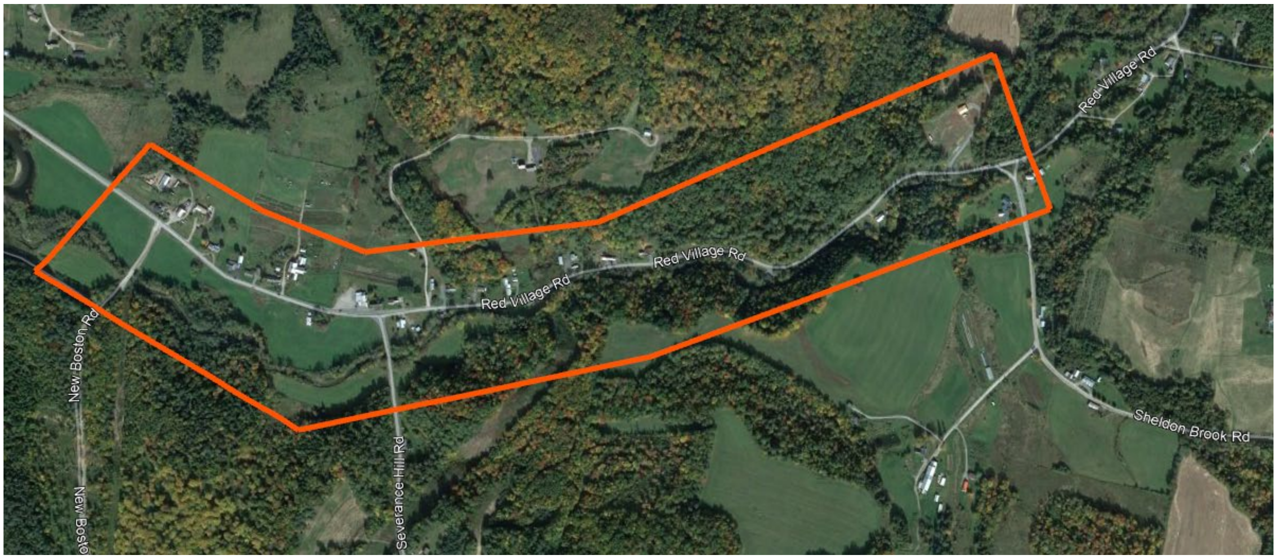


Figure 67. Intended AOI for LiDAR and imagery mapping, determined by reports of damage and scoping.

The LiDAR flight plan had been generated in the flight planning software UgCS (Figure 68). The KML of the approximate AOI was imported and a LiDAR flight block was drawn around the AOI. Parameters were set for the DJI Matrice 300 RTK to fly at approximately 60 meters AGL at 4 meters per second. The swath for LiDAR collection was indicated to be 85 degrees and flight lines were set to have 50% overlap as well as a double grid pattern. This combination of parameters were set to have the UAS fly lower and slower than usual, and have higher overlap as well. These measures were taken to improve the point cloud density and returns from the ground due to the higher vegetation in the area. The flight would therefore take longer than usual, with the intention of acquiring higher quality data over the complex terrain.

Figure 68. LiDAR flight plans in UgCS, separated into a Western block and Eastern block. The red "1" pinpoint indicated the first staging area of the UAS Team.

With the current launch and land zone on the western side of the flight plan, it was decided to begin with the more western flight block. The crew prepared the DJI Matrice and LiDAR sensor according to the pre-flight checklist, confirming that the hardware and software were ready for flight. One VO remained near the launch and land area with the RPIC while another VO dispersed further down the road to assist with airspace monitoring and discussion with folks on the ground if needed. The RPIC began flights at 12:46 EDT and throughout flight, the RPIC and two VOs kept eyes on the UAS and surrounding airspace to ensure the UAS was clear of obstacles, including other aircraft. Once the UAS reached low battery, the RPIC paused the automatic flight and returned the UAS to copy data and swap out batteries of the platform and sensor. Once ready for flight, the RPIC manually navigated the UAS back to the pause point and set the UAS to automatically continue its route. The entire western flight block took approximately 1 hour and 45 minutes to complete, with a total of three battery swaps. Because of limited line of sight beyond the western AOI, the UAS team determined that they would need to move positions in order to safely conduct the eastern AOI flights. With the washed out road and additional closures blocking the way to the other side of the AOI, there was no obvious way to reach the eastern portion.

To maximize usage of the current launch and land zone, the UAS Team began preparing for true-color mapping flights. The flight plans had been generated to cover the entire AOI (Figure 69). Parameters were set for the UAS to fly between 100-115 meters AGL at 12 meters per second. The front and side overlap were both set at 75%.

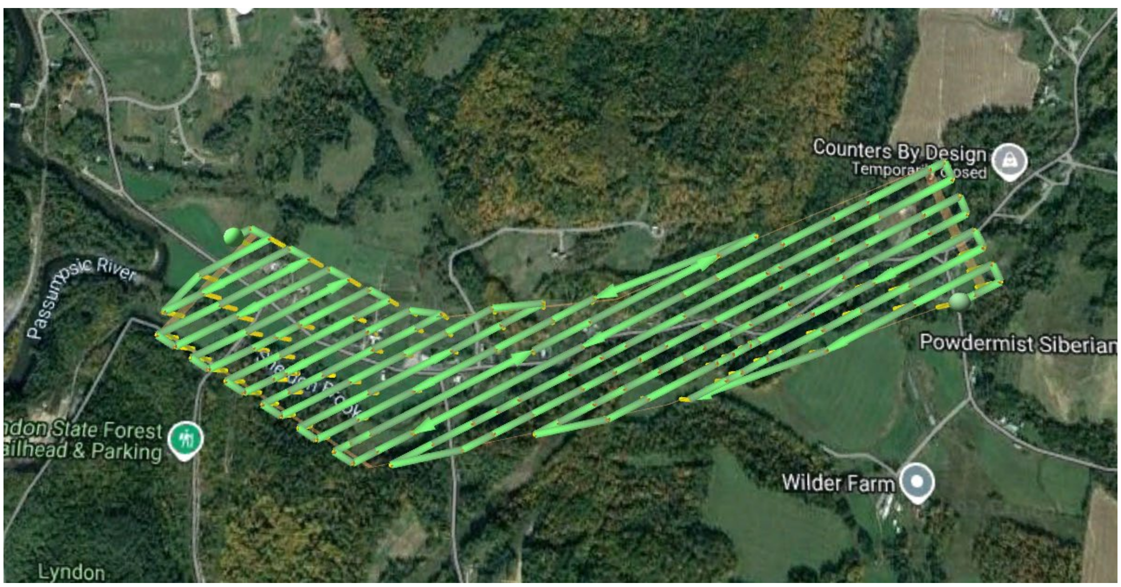


Figure 69. Imagery flight plan in UgCS, covering the entire AOI in one block.

The crew prepared the DJI Matrice with the imagery sensor according to the pre-flight checklist, confirming that the hardware and software were ready for flight. Connection was made via the controller to the Starlink wifi network, which enabled connection to the VRS for RTK. One VO remained near the launch and land area with the RPIC while another VO dispersed further down the again. The RPIC began flights at 14:45 EDT and throughout the flight, the RPIC and two VOs kept eyes on the UAS and surrounding airspace. Once the UAS reached low battery, the RPIC returned the platform, hot-swapped the batteries, and sent the platform to continue its route. The higher flight altitude compared to the LiDAR collection allowed the RPIC and VOs to keep line of sight with the UAS for the entirety of the planned AOI. The entire area took approximately 55 minutes to complete, with a total of one battery swap. The team attempted to begin processing imagery in the field using Site Scan, an online photogrammetric application, but were not successful in uploading the imagery, likely due to poor internet connection through the Starlink or insufficient upload speeds using the field laptop.

Following the completion of imagery collection for the entire area, the UVM UAS Team shifted back to determining how to complete the eastern LiDAR portion. This involved checking in with the UAS Team Lead and pilots from VTrans and USAR to get advice about where there could be accessible launch and land zones. Upon talking to locals and responders on the scene as well, it was determined that there was no feasible route to the other side of the road except for foot traffic or ATV usage. Due to the size of the platform, sensor, and associated batteries, it would not be possible for the team to walk the distance or catch a ride on an ATV with all of the equipment. There was a consideration that if there were two pilots each with a paired controller, one pilot could more easily get to the other side of the road while one pilot remained behind with the equipment. Since this was not possible, the team instead used Google Maps to scope out a better viewpoint on the western side of the road that they had access to and found a potential property uphill. A team member spoke to a group of landowners and were able to secure permissions to drive the team's vehicle through land and up the driveway to a higher vantage point.

At 17:12 EDT, the UAS Team was set up at the new vantage point and the first LiDAR flight for the intended eastern block began at 17:17 EDT. Within a few minutes, the UAS was beginning to follow the terrain down a hill, resulting in poor VLOS and Command and Control (C2) to the controller. The RPIC paused the flight and manually returned the UAS back to the landing zone. The automatic flight path was shortened to ensure the UAS would remain in line of sight with a strong connection (Figure 70). After successful reupload of the shortened flight block, LiDAR flights continued at 17:46 EDT and again at 18:14 EDT after swapping batteries.

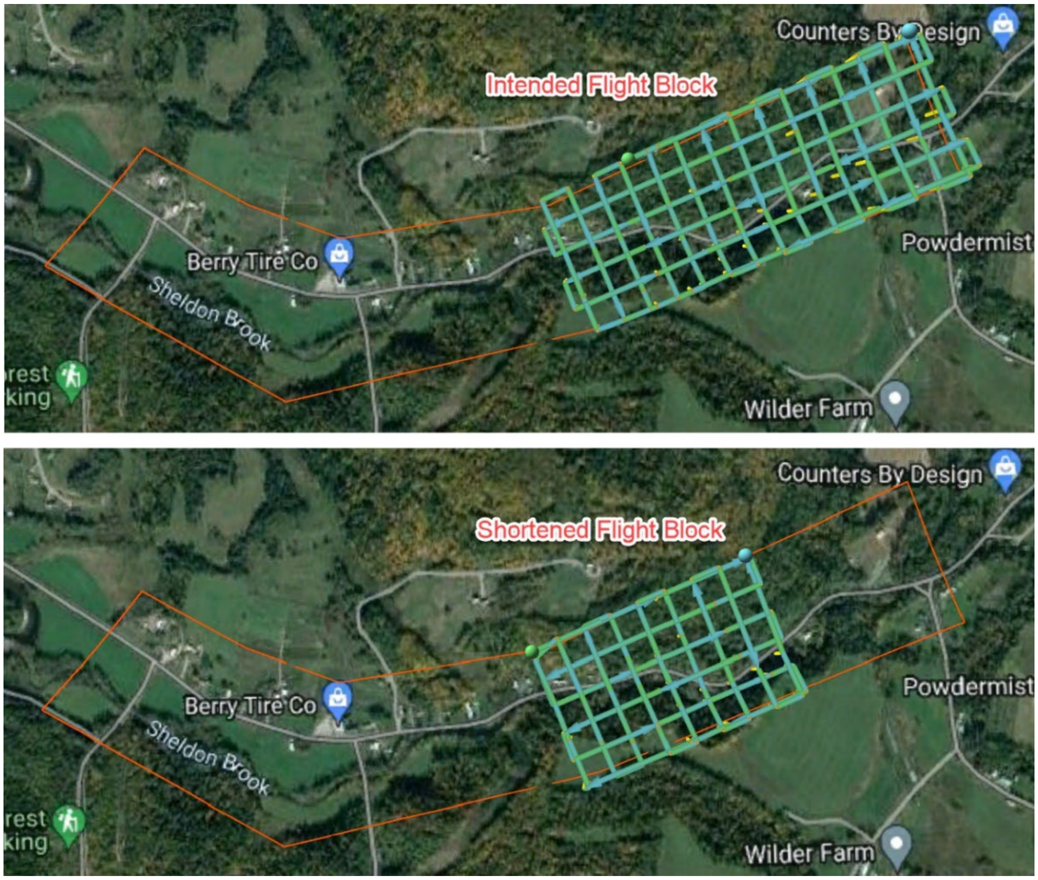


Figure 70. Eastern LiDAR flight block was intended to cover the rest of the AOI seen above but had to be shortened due to issues with line of sight and telemetry, resulting in the updated flight block seen below.

While the LiDAR pilot conducted operations with the DJI M300, one of the other team members used the DJI Mini to collect oblique photos and videos at 17:51 EDT and 18:04 EDT. The pilots communicated their intended flight paths to ensure a horizontal and vertical buffer between platforms at all times. The remaining VO assisted with monitoring airspace and helping to deconflict as platforms were coming in for landing.

By 18:40 EDT, the LiDAR collection was complete, and the team copied the data to the field laptop and checked for coverage. Despite not being able to cover the full area that was originally intended, the RPIC made the call to wrap up operations since there was no safe way to access the remaining area. By 20:30 EDT, the UVM UAS Team returned to the lab.

1.3.3.3 UAS Data Dissemination

Following completion of the flight operations, it was critical to share the collected datasets as rapidly as possible. Once the flight crew returned to the SAL, or as soon as possible the following day, the members copied the files from the field laptop and/or UAS SD cards to a UVM-hosted server system for shared access.

The data dissemination practices and workflows for this response event built off of the success and lessons learned not only during the Great Vermont Floods of 2023, but also as a continuation of the flood response efforts undertaken in response to the impacts of Beryl earlier in July 2024.

The oblique images and videos from the DJI Mini 3 Pro were reviewed and organized for sharing purposes. A selection of JPG-format images and MP4-format video files were zipped to a folder and uploaded to a Google Forms link that VCGI created to facilitate rapid sharing of these basic data products. From the ingest through Google Drive, the files were added to VCGI's Amazon Web Services storage buckets before being displayed as selectable points in a publicly accessible web mapping application. The points representing the images and videos could be displayed in the approximate position they were recorded due to the file metadata including the GPS coordinates of their capture (EXIF metadata within the JPG images and supporting SRT subtitle files aligned with the MP4 files). A screenshot of the web application is presented in Figure 71.

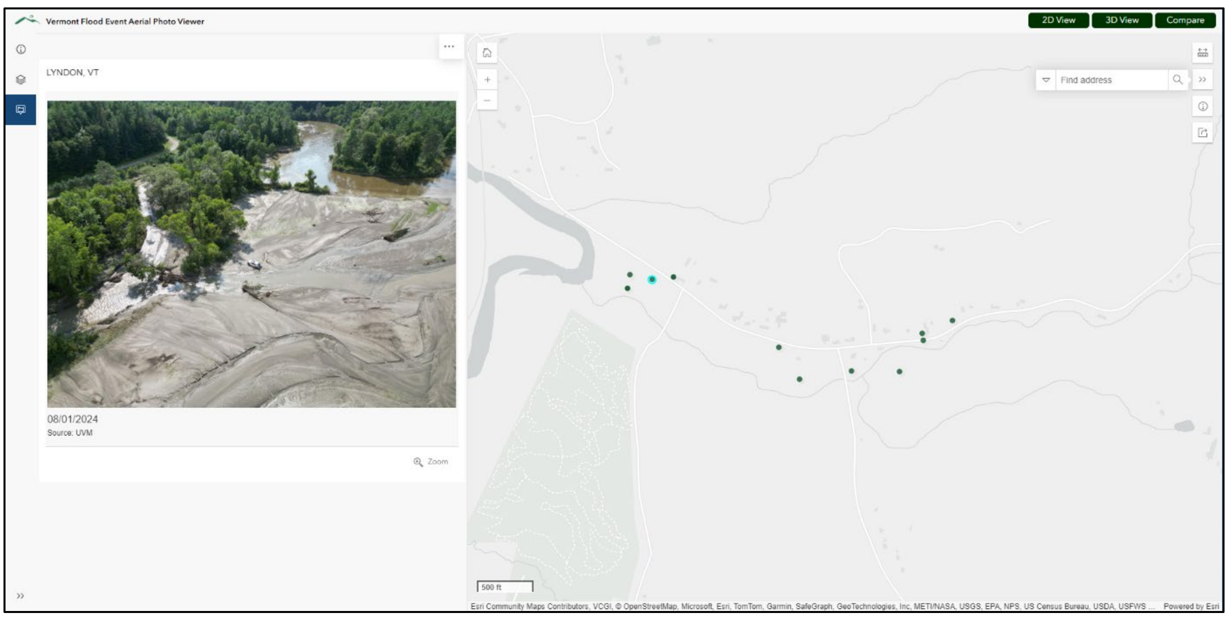


Figure 71. VCGI's web mapping application, containing points representing the approximate location that UAS images and videos were captured. The point with the teal circle is currently selected and the corresponding photo is displayed on the left side of the window.

The secondary data dissemination process for this event was to generate orthoimagery from the imagery captured during the mapping missions. Images from mapping missions were imported into SiteScan, a cloud-based application for photogrammetric processing. Following lessons learned from flood response in 2023, it was determined that this cloud-based solution had a number of advantages as opposed to localized processing, such as the ability to process many projects at once, reduce local storage needs, directly share products to AGOL, and simplify the processing workflow. The images were collected with RTK in the field, so there was no need for further geotagging steps back at the SAL, significantly cutting down processing time even more while keeping accuracy high. Once images were loaded in, the processing could begin online and continue even as the device or workstation was closed, allowing for background processing to occur as the UAS Team continued with other operations. The product of this processing included a 2D orthomosaic as well as a 3D integrated mesh.

1.3.3.3.1 St. Johnsbury

Operations in St. Johnsbury included two mapping areas, one of damage near the VTrans office on Route 5 (Figure 72) and one near Bridge 133 on Route 5. The collection of the bridge initially resulted in a fuzzy and low quality orthomosaic that was hard to interpret due to the low lighting conditions. A UAS Team member used Adobe Lightroom, a photo editing application, to increase exposure, shadow detail, contrast, white balance, and reduce noise (Figure 73). These settings were synched across all images to maintain consistency; the reprocessed orthomosaic with these changes resulted in a drastic improvement in interpretability. There were many areas that still appeared dark, however, highlighting the challenges with imagery capture as the sun goes down.

Figure 72. Orthomosaic of damage along Route 5 in St. Johnsbury collected by the UVM UAS Team on July 30.

Figure 73. Example of imagery from a UAS mission in low lighting before (left) and after (right) editing in LightRoom.

After imagery collection in St. Johnsbury, VTrans Highway Division Geotechnical Engineers requested elevation data of the landslide along Route 5 to be used to support their emergency slope stability analysis. While LiDAR data is especially valuable for DEM generation, it is also possible to generate a point cloud and elevation models through photogrammetric processing using imagery. To save time and expedite data delivery, it was decided to take advantage of the previous imagery collection that already covered the intended area and to simply generate new data products. A factor in this decision-making was that this fresh landslide had minimal vegetation remaining within the slide path, reducing the uncertainty of locating ground within photogrammetric models – unlike an active sensor such as LiDAR, data products produced through photogrammetry have limited capacity to penetrate through vegetation and only display the 'top surface' of the region. This novel workflow (Figure 74) involved photogrammetric processing and dense point cloud generation through Pix4dMapper software, which produced better results than SiteScan. QTModeler software was used to classify ground points and generate DEM files of 10cm/pixel and 30cm/pixel resolution. These DEMs were exported as LAZ files extensions, generating a point cloud file of the DEM with uniform point spacing, avoiding the data gaps associated with the low density of ground points found from the photogrammetric point cloud. These moderately sized LAZ files were convenient for geotechnical engineers to import to their CAD software packages for analysis. Figure 75 displays the 3D model generated by photogrammetry, the derived DEM, and elevation profiles of the current landslides as compared to previous aerial LiDAR.

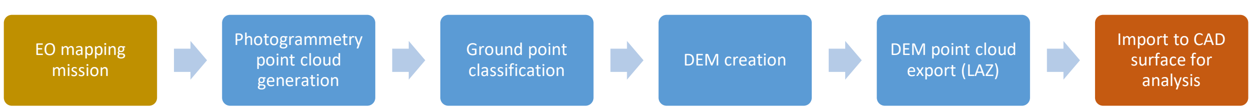


Figure 74. Novel workflow for integration of 3D photogrammetric products to CAD for use in slope stability analysis by geotechnical engineers.

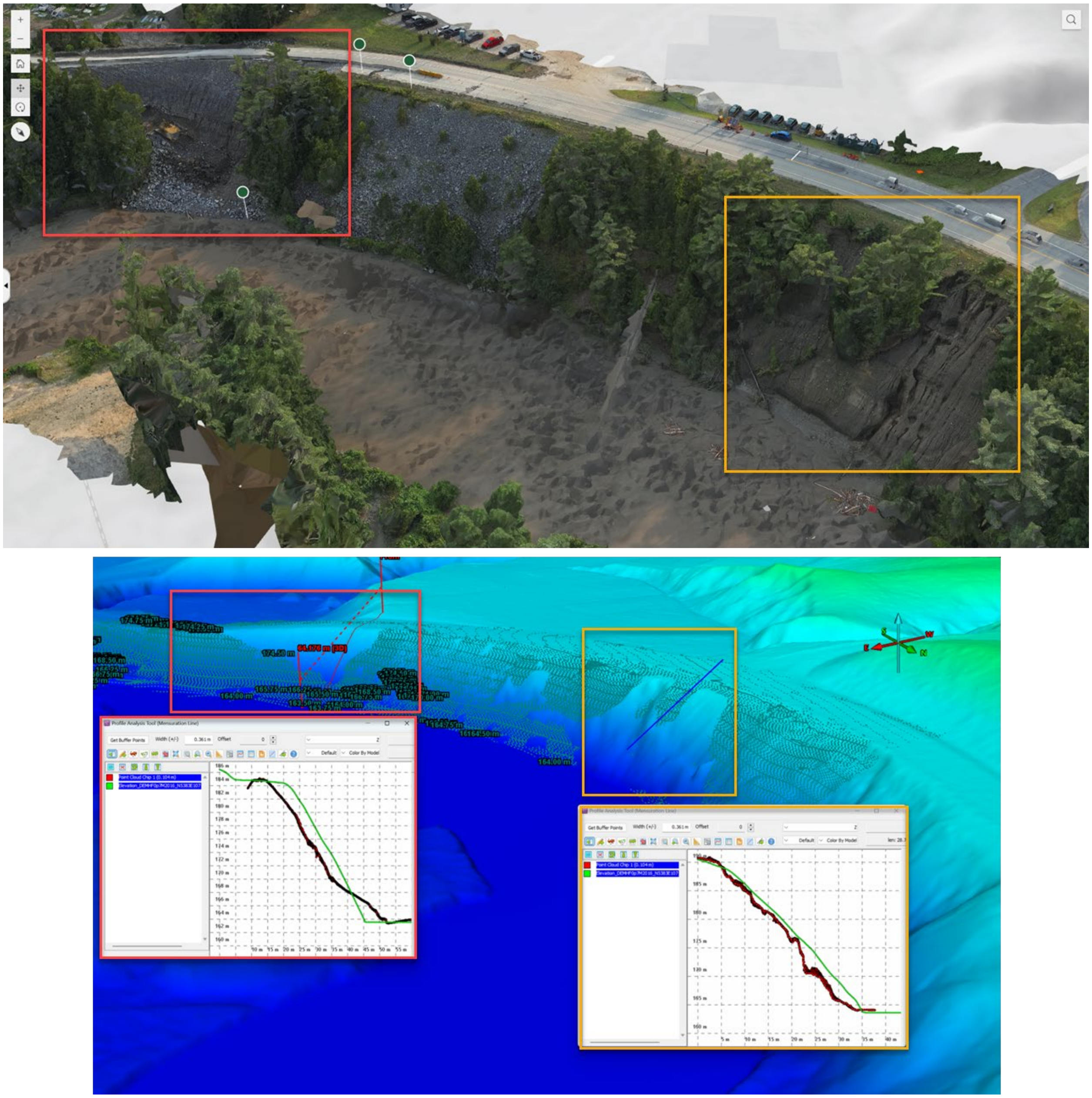


Figure 75. Route 5 landslides displayed in 3D mesh (top), accompanied by DEM and cross-section elevation profiles comparing the current elevations to previous aerial LiDAR data captured by the State of Vermont (bottom).

1.3.3.3.2 Lyndon – Red Village Road

Orthoimagery

For collections in Lyndon, the UVM UAS Team processed the imagery collected by VTrans as well as their own team, producing a long corridor orthomosaic (Figure 76) as well as an orthomosaic representing a smaller region (Figure 77).

Figure 76. Orthomosaic of corridor along Red Village Road in Lyndon, collected by VTrans on August 1 and processed by the UVM UAS Team.

Figure 77. Orthomosaic of smaller focus area along Red Village Road in Lyndon, collected by the UVM UAS Team on August 1.

Upon completion of each orthomosaic processing, a UAS Team member began directly publishing the imagery to a tile service. Once published, sharing permissions were adjusted to allow public access and the items were added to a designated AGOL group created by the UAS Team Lead for editing and access by other UVM UAS Team or VCGI members. A member of the UVM UAS

Team would then notify VCGI via email once products were uploaded and ready for integration to their public web mapping application. The web application has a built-in feature allowing for powerful comparisons between UAS orthomosaics and pre-flood imagery, as seen in Figure 78. Exact timing for the processing and online integration varied by each mission but was completed within the range of 12-72 hours. When possible, a UAS Team member also made a copy of the orthoimagery file in GeoTiff format, adjusted the naming of the file to meet the SAL's standard conventions, and saved it to the SAL's servers for storage redundancy. VCGI was provided with links to COG files produced by the SiteScan software, which they planned to use to allow for 'data streaming' into GIS programs.

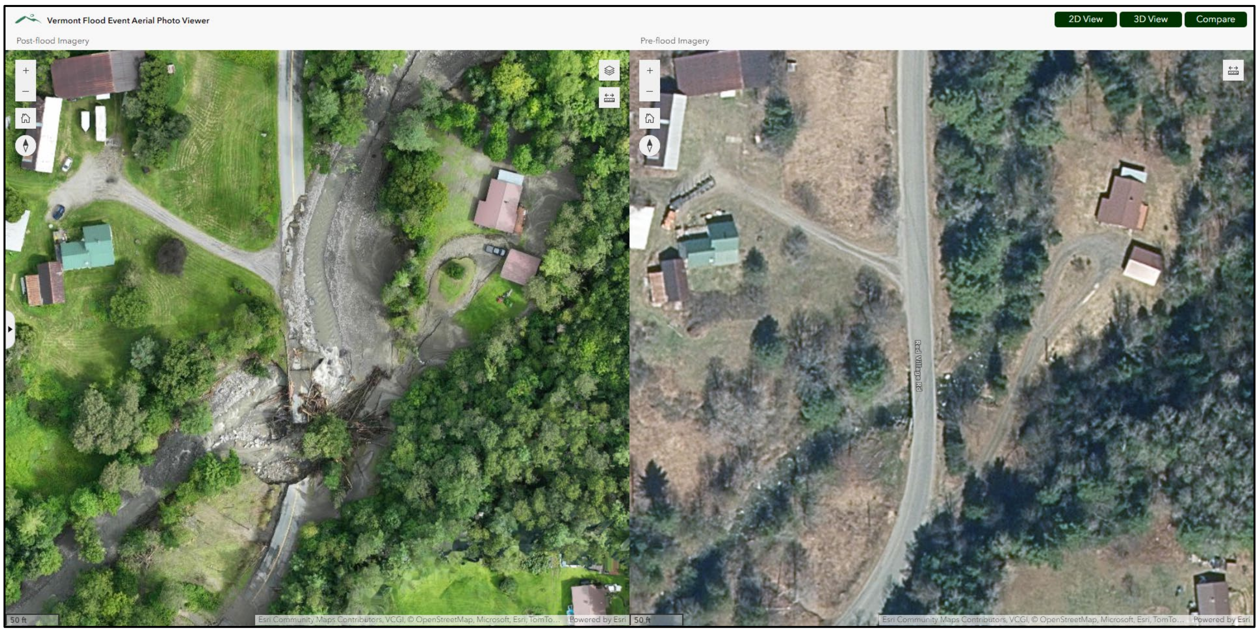


Figure 78. Vermont Flood Event Aerial Photo Viewer, showing a comparison of post-flood UAS imagery (left) and pre-flood imagery (right) in Lyndon.

LiDAR

The Lyndon LiDAR data processing began with PPK corrections of the flight trajectory using Applanix POSPac software and data from a nearby CORS station. A point cloud was generated using YellowScan CloudStation software and the corrected trajectory. Utilizing LAStools software, the point cloud was classified to differentiate between ground and above ground features, and then used to generate a DEM representing bare earth, which was of highest interest to stakeholders (Figure 79). The high density point cloud originally caused issues with model generation, so it was cropped and the density reduced in QT Modeler to allow for successful production of the DEM. The DEM file was then zipped and transferred to a River Management Engineer at Vermont ANR for immediate use in analysis. For public viewing, the DEM was imported into ArcGIS Pro, a hillshade was generated, shared to AGOL and ingested by VCGI for the web app viewer. The viewer also allowed for comparison of pre-flood LiDAR collected by the state (Figure 80). The UAS LiDAR derived data products allow for 3D visualization of the scene and for highly detailed measurements of distance, height, area, and volume. Due to the high accuracy of these products (often in the range of 1-2 inch in horizontal and vertical planes), comparisons can be carried out to determine topographical changes that may have resulted from the flooding event.

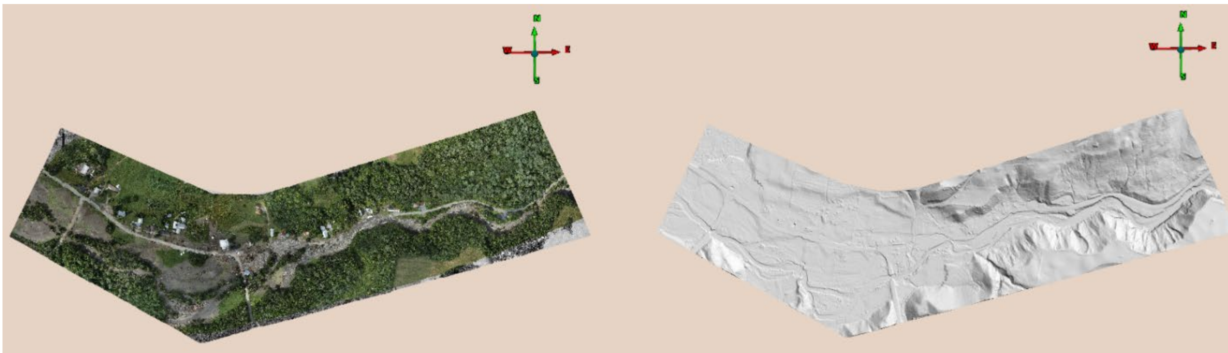


Figure 79. Colorized and classified point cloud (left) and resulting DEM (right).

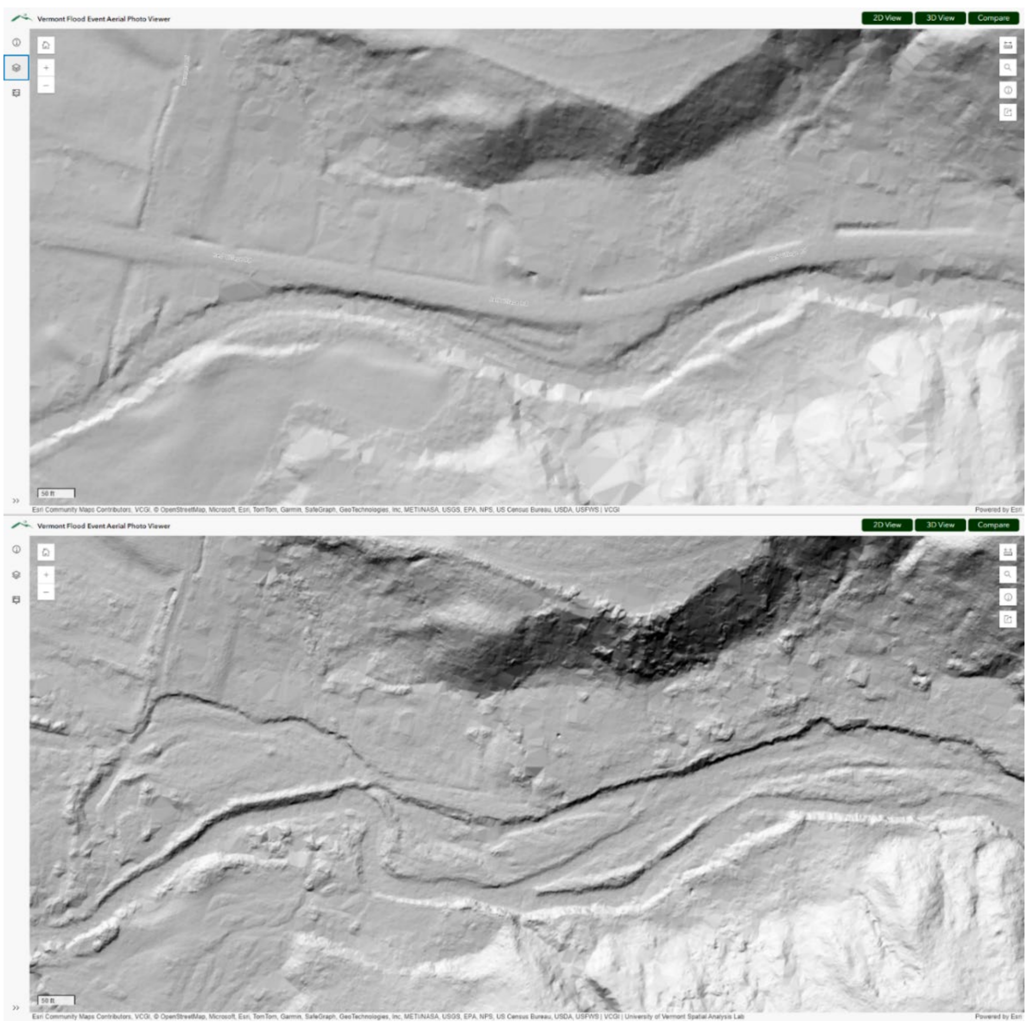


Figure 80. Comparison between pre-flood LiDAR DEM collected by the state via manned aircraft (top) and UAS LiDAR DEM collected by the UVM UAS Team in Lyndon on 08/01 (bottom). There is visible erosion and washouts from the rain and flooding.

1.3.4 Flood Response Functional Exercise Follow-Up Activities, If Applicable

Throughout UAS mission tasking and as a follow-up to each flight operation, data management was a crucial process to ensure organized record keeping, efficient UAS product generation, and successful data dissemination. Many of these techniques for data management were established during 2023 flood response and further refined during earlier July 2024 flood response operations. An excel tracking spreadsheet was utilized as a singular document for the UVM UAS Team to internally keep record of each UAS flight date, location, purpose, RPIC, platform and sensor type, file locations, and status of processing, publishing, and delivery to stakeholders, among other information. Even further attention to detail provided automations to the spreadsheet to fill in cells based on previous choices, color code selections, and other functionality that would facilitate the data management process and save time. The SAL maintained existing standard practices for folder structure and organization, file naming conventions, and metadata management for UAS data. This was crucial to ensure that even in stressful situations, flight crews, data managers, and supervisors could reliably know where to locate datasets and verify that completed products were shared with VCGI for greater public dissemination.

The UAS data products generated from this exercise and made publicly available through VCGI were utilized for decision making by local and regional stakeholders, as well as made available to FEMA for analysis in geospatial damage assessments.

- The data from St. Johnsbury was valuable for VTrans Highway Division to assess slope stability along landslides. The UAS point cloud produced from photogrammetry was able to provide enough detail for VTrans to interpret two failure areas and better understand the height of the slope as well as existing and proposed grades prior to repairs.
- The long corridor flight operations that VTrans conducted in Lyndon were crucial for identification of debris in the river near Red Village Road. The debris, which had built up in critical areas, threatened both infrastructure and the river’s flow. The RPIC took multiple images of the affected areas, highlighting access routes for the contractors and providing GPS coordinates for easier navigation. The UAS’s high-resolution imagery provided precise locations of debris piles, which were later used by contractors to remove obstructions.
- The orthoimagery and DEM of the focus area that the UVM UAS Team covered in Lyndon was of particular value to the Agency of Natural Resources. The rapid geospatial products with high spatial resolution and accuracy were key for the agency to assess flood impacts prior to road building and river work, including emergency river re-alignment.
- Data could be accessed by local residents, town emergency managers, local road crews, regional planning commissions, state agencies, or other interested stakeholders for visualization, analysis, and continued monitoring and planning moving forward.
- Orthoimagery and oblique images/videos were made accessible to FEMA’s Region 1 GIS team for integration to FEMA teams carrying out Preliminary Damage Assessment (PDA), which was requested on August 1 and provided to the Office of the Governor of Vermont on August 12.

Following completion of flights in St. Johnsbury and Lyndon, the UAS Team continued operations in additional areas as requested to capture more data of damage from the flooding. Between July 1 and October 15, 2024, VCGI’s 2024 Flood Event Aerial Photo Viewer received 43,434 requests with an average of 409 requests per day (Figure 81). Access to these data for this flood event had numerous daily peaks between August 1 to August 13.

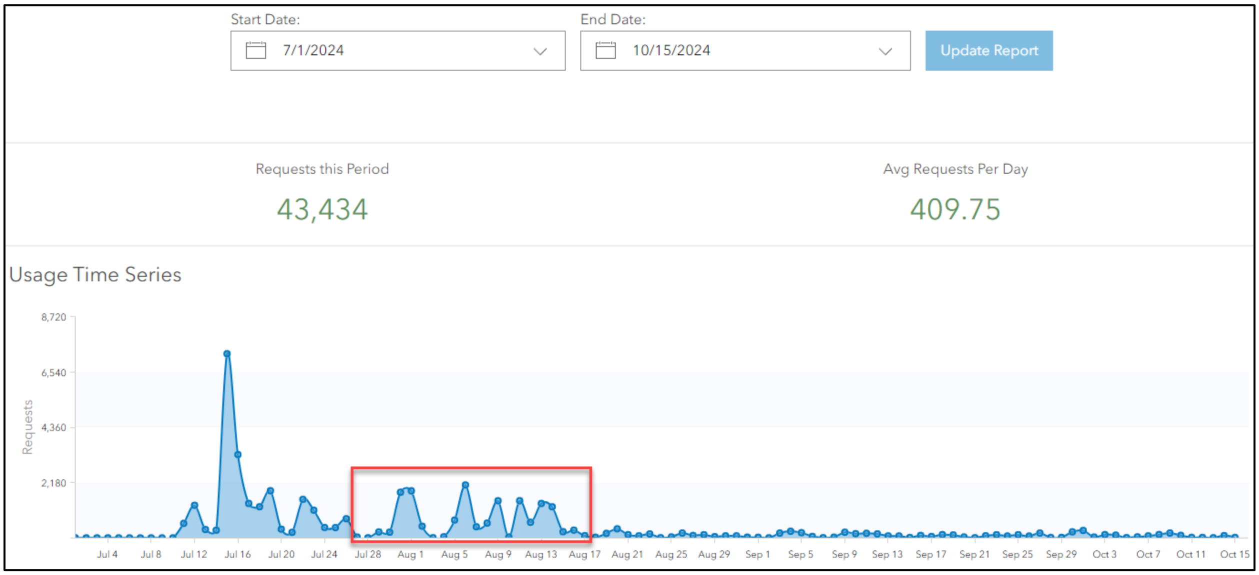


Figure 81. Usage statistics of VCGI's Flood Event Web Application, with July 30, 2024 flood event usage highlighted in red box.

1.3.5 Lessons Learned from the Flood Response Event, Including Responses to Research Questions

1.3.5.1 Flood Response Event Key Findings:

- Requests by individual agencies were able to guide UAS response and produce valuable data, but teams would benefit from more organized tasking and response operations under the EOC and ICS for future response efforts. This would streamline requests, improve efficiency, and potentially minimize funding limitations.
- Without direct tasking, a combination of resources can be useful in prioritizing areas to respond to including local rainfall estimates and flood gauges, news reports of damage and insight from response agencies.
- Following a disaster event, road closures and washouts can make it challenging to access sites for UAS collection.
- During an emergency response, multiple UAS teams may be responding to the same area, resulting in a need to communicate and deconflict airspace.
- Maintaining VLOS and C2 to the UAS can be difficult depending on the access and terrain of the response area, potentially limiting operations until more suitable access sites become available or the availability of BVLOS provisions.
- Emergency response and natural disasters are unpredictable and therefore it is crucial for UAS pilots and teams to have flexibility in terms of equipment, operation areas, flight planning, automated vs manual flight, and other aspects of operations.
- A combination of manual flight and automatic triggering of images can collect useful data when automated flight plans are not feasible. If done correctly, even a singular pass along a corridor can produce suitable mapping results without significant requirements for automated flight planning.

- Mapping imagery collection towards dusk can result in poor interpretability of features in the orthomosaic, but could potentially be rectified through editing.
- RTK or PPK collection will improve UAS data accuracy, but RTK imagery collection is especially helpful for speeding up processing times by eliminating the need for geotagging the photos
- Processing mapping imagery in a cloud-based environment allowed multiple members of the UAS Team to begin processing online while they continued other operations, improving the ease and speed of orthomosaic generation. There are still limitations to processing in the field, however, due to slow speeds over wifi networks.
- LiDAR collection may be more limited than imagery collection due to the typical lower altitude during flights which can inhibit VLOS and C2.
- LiDAR processing takes significantly longer to process than imagery, requires specific software, and involves more complex workflows that could present challenges and setbacks.
- UAS photogrammetric point cloud generation can provide suitable CAD integration for geotechnical engineering solutions/
- A public web application containing multiple types of data from the three flooding events, comparison views between pre- and post-flood imagery, and 3D capabilities were a valuable resource for stakeholders to view affected areas, identify debris, document damage, and more.
- The data sharing workflow from UVM's SiteScan projects, directly to AGOL, and into a designated group with VCGI allowed for rapid integration into public applications made available to FEMA, state agencies, and members of the public.
- Internal practices including pre-flight checklists, pre-mission checklists, data tracking spreadsheets, workflows and SOPs were essential in carrying out safe, efficient operations and organized data processing and delivery.

1.3.5.2 Flood Response Functional Exercise Recommendations:

- There is a need for direct tasking from the EOC to the UAS team to facilitate rapid response, help with site prioritization, and create a standardized tasking and data delivery protocol. The development of a state-wide or regional UAS tasking tool, including the ability to define tasking areas using geospatial layers and describe the types of data products desired, would be particularly valuable to direct UAS resources appropriately during an active response event.
- To gain safe access to response sites for UAS operations, it is recommended to check local or regional road closure sites, collaborate with the state's transportation agency, and connect with responders on site to confirm a suitable staging area.
- Further develop coordination protocols and tools to assist with multiple UAS teams responding in the same area. It would be especially valuable to allow responders to view where data has already been captured, prevent duplication of effort, and facilitate deconfliction of airspace when relevant.
- When experiencing challenges with VLOS and/or C2, a number of tactics could improve flight coverage such as moving the launch and land area to a more suitable location or utilizing dual controllers to allow multiple pilots to take control from different vantage

points. The RPIC should also be prepared to balance collection efforts with safe operations, and make calls if flights are not feasible.

- Develop additional training materials and/or pathways to allow emergency responders to be aware of the possibility of conducting BVLOS operations and knowledgeable on how to request such a COA/waiver under the SGI request process.
- To allow for flexibility in the field during UAS emergency response, consider packing multiple UAS and sensors, be willing to scout out various staging areas to fit the needs of the mission, and prepare to flight plan in the field or carry out manual flight for imagery collection. This level of adaptability for a PIC or team, especially when it comes to manual flight, should be improved through hands-on flight practice, drills and exercises, and continual review of best practices and lessons learned.
- Research, develop, and test out best practices for manual mapping of an area using automatic triggering of images to expand mapping capabilities when automatic flights are not possible.
- When possible, aim to complete collections before dusk to avoid flying in poor lighting conditions. If necessary, adjust camera settings to compensate for low light, including faster shutter speeds and the capture of RAW files to allow for easier adjustments. If images appear too dark, a number of steps can be carried out in photo editing applications such as increasing exposure, shadow detail, contrast, white balance, and/or noise reduction.
- When possible, collect mapping imagery with RTK to avoid the need for additional post-processing steps to improve accuracy. Increased accuracy allows for more reliable comparison to previous and future UAS and aerial datasets.
- During emergency response or operations that are time-critical, consider using cloud-based processing environments to maximize processing capabilities and more easily integrate products into online services. Further development of technologies and/or protocols are needed, however, to improve processing in the field with slower internet or less powerful devices.
- Further research is needed to determine methods for improving LiDAR collection such as advancement of sensors to allow for higher flight altitudes without compromising data quality, or easier access to BVLOS operations during critical response operations.
- When possible, focusing on imagery collection and processing will speed up UAS product generation and provide stakeholders and decision makers with data sooner. If LiDAR collection is needed, it is recommended to develop workflows and standard operating procedures to improve efficiency. Software advancements that simplify UAS LiDAR processing and elevation model generation would be extremely valuable.
- When UAS -LiDAR collection is not feasible or efficient, consider using photogrammetric processing of UAS imagery to generate point clouds and elevation models for analysis. This could maximize capabilities and expand data types available for response and recovery efforts.
- To maximize utility of UAS data products after collection, prioritize setting up a public facing application that is easy for end-users to access, navigate, make comparisons, and analyze data products.
- Develop and refine protocols for processing and sharing UAS data rapidly so that FEMA, state agencies, and other stakeholders have access as soon as possible. Consider using

cloud-based processing sites, such as SiteScan, that can directly integrate into online mapping applications like AGOL. When possible, it is recommended that there are designated data managers besides the UAS pilots to facilitate this process

- It is crucial that UAS Teams develop and refine internal practices that will guide procedures, allow for safe operations, keep data organized, and speed up processing and dissemination. These methods should be debriefed and improved upon through exercises, drills, and real-world UAS operations.

1.3.5.3 Flood Response Functional Exercise Informed Research Question(s):

1. How effective are the policies, procedures and guidelines used in the exercises?
    - Internal policies allowed for quick approval for UAS flight operations through UVM Risk Management, and no further airspace approval was required for Class G airspace, allowing for rapid deployment. The most hindering policy was VLOS requirements under Part 107, which limited the size of the collection area.
    - Typical procedures and guidelines followed by the UVM UAS Team were effective at capturing useful data and quickly disseminating it to the public. These protocols have been developed and refined over many years and countless flood responses, and are always evolving, highlighting the need for continued exercises and constant reflection.
2. When a disaster or emergency happens, what should future coordination with federal governmental agencies look like when UAS are fully integrated into the NAS?
    - More direct and streamlined tasking and requests from agencies to UAS teams and operators are needed. This should involve the establishment of strong relationships between agencies and UAS operators, as well as ongoing rapport and collaboration, not just when a disaster or emergency happens.
    - Improved tools for airspace coordination and deconfliction, with clear communication pathways to solve issues that arise
    - Standardized data transfer procedures, with the ability to receive updates and feedback about how the data is being used by federal agencies
3. What are the considerations of disaster and emergency UAS Traffic Management (UTM) during manned/unmanned joint operations?
4. What are the considerations of evolving cyber security?
5. What UAS-related technological advances will benefit the use of UAS in a disaster or emergency response?
    - UAS platforms and sensors that are more weather-resistant, allowing for flight operations during rain, high wind, or other current barriers.
    - Improvement to C2 links to expand the distance that UAS can reliably fly away from the pilot, expanding flight capabilities and BVLOS capacity.
    - Robust data storage options, more direct data transferring, quicker processing methods, or other techniques to simplify and speed up the data dissemination following a response.
6. What are the barriers to entry for local, state and federal organizations employing UAS technology for disaster and emergency response and recovery?
    - Cost of UAS technology and barriers to affordable options or funding.

- Lack of expertise and knowledge about how to best employ UAS technology for specific mission profiles.
- Volunteer base that is not always available for training or operations.
- Knowledge gaps regarding request for BVLOS wavier/COA during emergency UAS operations.

7. What enabling technologies or advancements would aid future disaster preparedness and emergency response?
   - Technologies that track UAS and occupied aircraft in the NAS across multiple organizations, so operators are aware of ongoing flight operations in their intended response area to successfully deconflict airspace and avoid collisions.
8. What data should be gathered to support lessons learned and process improvements?
   - How often do UAS operators shorten their intended flight area or miss crucial data due to VLOS limitations
   - What methods are successfully being implemented to track multiple UAS operations in the same airspace
   - What entities use the UAS data during or following an emergency response, what data types were most beneficial for their specific use cases, and other information that will help reflect on and improve procedures to best support the communities in need
9. Propose future disaster preparedness and emergency response certification standards.
   - Training to prepare and certify pilots for BVLOS operations, with an emphasis on risk mitigation during a disaster or emergency event

1.3.5.4 Flood Response Functional Exercise Lessons Learned Summary:

UAS played a crucial role in the response to the severe flooding events that took place in the NEK in late July 2024. A combination of resources and insight from local and regional agencies allowed for prioritization of sites for UAS response, however it was identified that direct tasking from the EOC as soon as possible would have been beneficial as well.

On site, UAS enabled rapid deployment and data collection in areas that were otherwise inaccessible or hard to reach due to road closures and washouts, proving invaluable in capturing timely data for road and landslide repairs. While manual flight of a small multirotor UAS platform worked well for quick scoping of an area and oblique photo and video capture, larger multirotor platforms with the ability to swap out payloads and conduct automated flight were valuable for capturing mapping imagery and LiDAR datasets. When constrained by platform and challenging terrain, however, manual flight of a multirotor with automated photo capture was successful in collection of imagery for photogrammetric processing, highlighting the need for manual flight expertise and flexibility while in the field. Throughout operations, it was critical to ensure airspace was clear and there would be no interference from other aircraft, identifying a need for a coordination tool to assist with airspace tracking and deconfliction.

Processing imagery datasets in a cloud-based application was extremely helpful for more efficient and streamlined processing. This allowed for direct sharing to AGOL, which expedited the process of getting data to VCGI who could consolidate products into a singular online web application easily accessible to the public or stakeholders such as FEMA. There are still challenges surrounding image upload speed and processing while in the field, however, and challenges surrounding the complexity of LiDAR processing. The data collected from UAS operations offered a comprehensive view of the damage to infrastructure and erosion of waterways, supported detailed assessments of landslides and debris, and served as essential documentation for future flood resiliency research and planning efforts.

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Appendix J. Kansas State University Task 7 Report

The FAA's Center of Excellence for UAS Research
ASSURE
Alliance for System Safety of UAS through Research Excellence

K-STATE

Kansas State University
ASSURE A62

A62 KSU UAS Test Plan
(Kansas State Fair)

August 15, 2024

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TABLE OF ACRONYMS

COA	Certificate of Authorization
COP	Common Operating Picture
EMS	Emergency Medical Services
EO	Electro-Optical
FMV	Full Motion Video
KDOT	Kansas Department of Transportation
KSU	Kansas State University
MITRE	The MITRE Corporation
RPIC	Remote Pilot in Command
TAK	Team Awareness Kit
UAS	Unmanned Aircraft System
VO	Visual Observer

1. INTRODUCTION

This document provides the test plan for Kansas State University (KSU) effort in A62_ A11L.UAS.68: – Disaster Preparedness and Emergency Response Phase III (hereinafter A62). Details on the event logistics, participants, locations, and communications plan, and objectives are identified within the document.

1.1.1. Project Overview

This research project aims to explore how Unmanned Aircraft Systems (UAS) can be safely integrated into disaster response efforts. It will investigate the effectiveness of using UAS to respond to various natural and human-made disasters, focusing on coordination protocols among federal agencies like DOI, DHS (including FEMA), and local/state emergency response organizations. The findings will inform the development of requirements, technical standards, and regulations necessary for UAS operations in disaster response and recovery. Additionally, the project will establish a database of collected data to analyze pilot proficiency and overall performance in UAS flight environments, building upon previous research phases.

1.1.2. Scope of Live Event

While UAS testing involved in A62 primary focuses on executing Mock Event Demonstrations, KSU will inject UAS directly into a live event at the Kansas State Fair. KSU will integrate custom UAS software to deliver real-time data directly to the Incident Commander, through use of a Common Operating Picture (COP). The oriented goal is to significantly improve communication and response time between Incident Commanders and public safety officials in the active environment. KSU will incorporate, test, and validate the COP software and hardware the state of Kansas has been developing for large-scale events. Operating within a live event with interagency support and live emergencies, mirrors disaster response operations and provides a unique opportunity to the enhance interagency collaboration seen during disaster response efforts.

The purpose of UAS flights during the event is to measure and validate performance of the following data collection types and methods:

- Multiple UAS systems airborne within shared airspace, with activity directed by the Incident Commander.
- Aerial video livestreaming to local and remote emergency command facility to provide situational awareness.
- Assess the usability and effectiveness of the COP/Team Awareness Kit (TAK) system for enhancing situational awareness among public safety officers monitoring the crowd.
- Evaluate how well the system supports communication and coordination between officers and with the command center.
- Determine if the system helps officers identify and respond to incidents and distress calls more quickly and effectively compared to not using the system.
- Gather feedback from officers on pain points, areas for improvement, and additional capabilities that would be helpful.
- Determine if upgrades to the TAK equipment and software improved the overall operation of the COP.

For these operations, KSU will utilize the most common UAS utilized by public safety and will be deployed to determine effectiveness across platforms. Testing these capabilities will enable identification of gaps in current abilities and focus efforts on what future development and training is needed. Specific objectives for this test are outlined in the following section.

2. OBJECTIVE

The primary test objectives are:

1. Reduce communication barriers between incident command and public safety officials in the field across multiple jurisdictions and public safety entities.
2. Ability to provide multiple sources of information to incident command via the COP, to make timely and information driven decisions. These include but are not limited to:
    - Map overlay of the active area
    - Location of ground and air assets
    - Real-time Full Motion Video (FMV) feeds from multiple ground and air sources
    - Real-time location of public safety officials on the ground
3. Disseminate UAS data, including FMV and imagery to a remote location(s), simulating information being sent up the chain of command.

3. EVENT ARCHITECTURE

The live event testing at the Kansas State Fair was chosen to replicate the complex multi-jurisdictional and multi-agency operations typical of large-scale disaster response efforts. Live event flights will take place at the State Fair Grounds located in Hutchinson, Kansas with an anticipated attendance of 350,000 people over 10-days. This venue will involve collaboration among various public safety agencies, including local and county law enforcement, fire departments, and Emergency Medical Services (EMS).

Preliminary findings from A52 (Phase II) underscored significant communication challenges observed in mock exercises, particularly exacerbated by multi-agency and jurisdictional coordination. Variances in communication methods, standardized protocols, and overall situational awareness deficiencies have highlighted pervasive communication issues. The COP proposed for this event aims to address these challenges by providing the Incident Commander with comprehensive situational awareness, enabling real-time visualization of officer locations and, when applicable, live footage from UAS or ground cameras to direct assets.

To avoid disrupting ongoing incidents, an Incident Commander Liaison will be stationed at the primary COP display. This person is a law enforcement officer experienced in UAS operations and event at this venue. With live actionable data at their disposal, this individual can relay critical information to the Incident Commander and if authorized, officials in the field. Refer to the Communication Plan for communication structure.

4. AIRCRAFT & TEST SPECIFIC EQUIPMENT

The KSU UAS Team will deploy the assets presented in Table 1-4 onsite to support the flight testing.

Table 1. KSU UAS Asset Descriptions.

Asset	Category	Description
Mobile Command Trailer	Operations	18' mobile command trailer to run COP and store equipment
Traffic Cones	Safety	Small traffic cones to delineate takeoff & landing areas.
Motorola Handheld Radios	Communications	Motorola handheld radios allow for two-way radio communication between the Incident Commander Liaison, Incident Commander and field officers.
Airband Radio	Communications	Airband radio enables RPICs to monitor local air traffic
Starlink	Communications	Network connectivity will be provided through a portable Starlink system.
High Visibility Vests	Safety	To promote visibility and safety among all involved participants.
Computer/Servers	Flight Operations	To run the COP and transmit data to remote location(s)
First Aid Kit	Safety	In case of any minor first aid requirements.
Whiteboard	Flight Operations	To be utilized by the Air Boss for planning, airspace deconfliction, and other visual-based scheduling.
Water Jugs	Safety	Ice water will be available to crew and support teams
Sun Screen	Safety	Sunscreen will be available to all teams
Access Badging	Communications	To easily identify each other, along with visually separating flight teams (if needed).
Skydio X2	Flight Operations	Common public safety UAS will be used for testing
Skydio X10	Flight Operations	Common public safety UAS will be used for testing
DJI Matrice 300	Flight Operations	Common public safety UAS will be used for testing
Static Cameras	Flight Operations	Common public safety static cameras will be used for testing
End User Devices	Flight Operations	End user devices (cellular) will be used to track officers in the field for testing

Table 2. Description of Skydio X2.

UAS Operator	KSU	**Sensors**	EO/IR

Manufacturer, UAS Type	Skydio, Multirotor	**Wingspan**	26.1 in
Mission Role	Surveillance/FMV	**Maximum Takeoff Weight**	2.49 lbs.
Flight Type	Manual	**Endurance**	25 min

Table 3. Description of Skydio X10.

UAS Operator	KSU	**Sensors**	EO/IR
Manufacturer, UAS Type	Skydio, Multirotor	**Wingspan**	31.1 in
Mission Role	Surveillance/FMV	**Maximum Takeoff Weight**	4.65 lbs.
Flight Type	Manual	**Endurance**	40 minutes

Table 4. Description of DJI Matrice 300.

UAS Operator	KSU	**Sensors**	EO/IR
Manufacturer, UAS Type	DJI, Multirotor	**Wingspan**	35.23 in
Mission Role	Surveillance/FMV	**Maximum Takeoff Weight**	19.8 lbs.
Flight Type	Manual	**Endurance**	40 minutes

5. FLIGHT LOCATION

Flight operations will occur at the Kansas State Fair Grounds in Hutchinson, Kanas as illustrated in Figure 1. The center of the operational area is at the coordinates 38° 4'40.85"N, 97°55'32.40". The flight operations area falls within Class D airspace as illustrated in Figure 2. Flights will be conducted under an FAA Public Certificate of Authorization (COA) #2023-CSA-15089. Remote Pilot in Commands (RPICs) will monitor local traffic on 118.5.

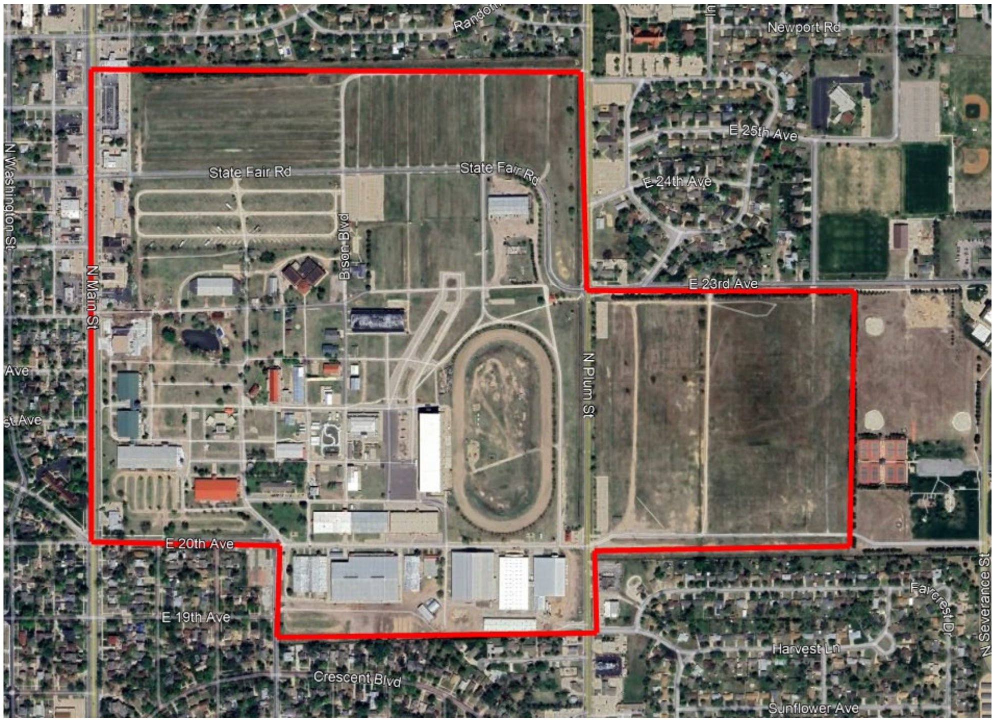


Figure 1. Illustration of the flight area, highlighted by polygon shown.

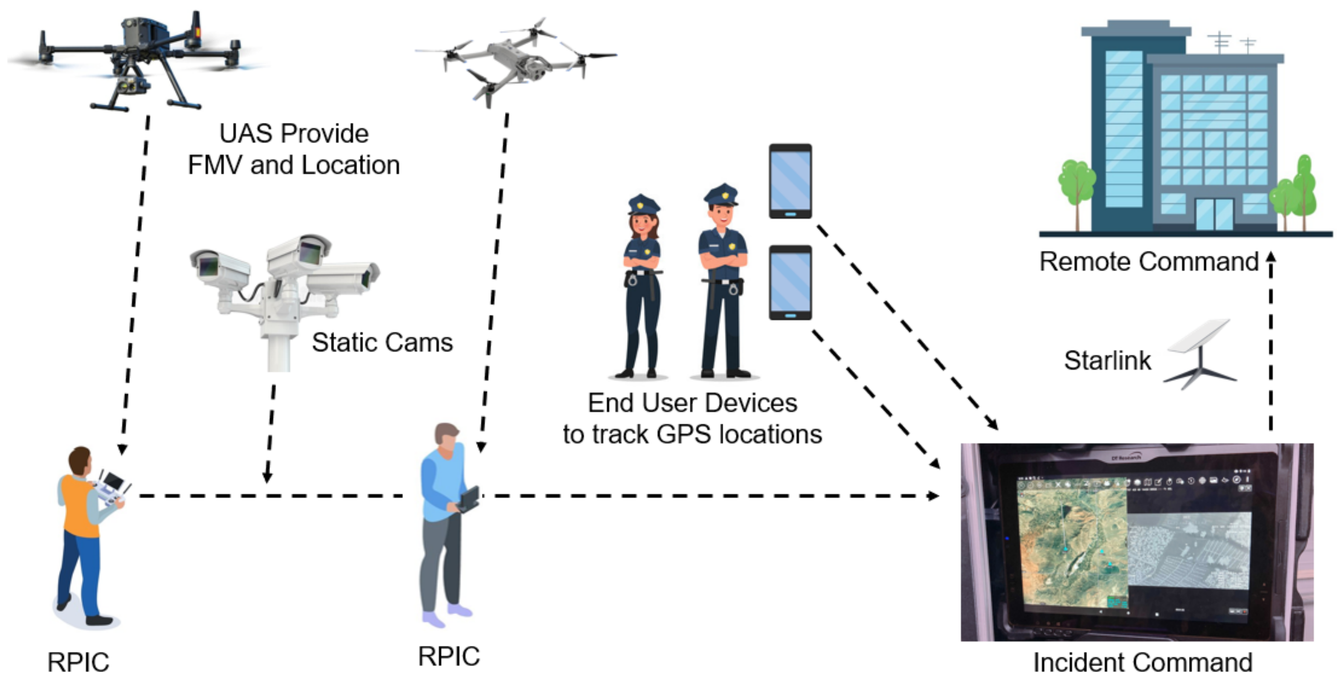
Figure 2. Illustration of the flight area on Sectional Chart, in red.

6. COMMON OPEREATING PICTURE

The Kansas Department of Transportation (KDOT) and The MITRE Cooperation (MITRE) developed the COP to further enhance disaster response efforts across the state and nation. The software for the COP is the TAK. TAK is a suite of georeferenced imagery, live video, and communications tools that allow for scaled operational planning, data sharing, visualized elevation data, and target management.

Although the base TAK integration provides significant advantages over siloed UAS operations, KSU has worked with KDOT and MITRE to develop a custom version more specific to UAS operations and common disaster response efforts. Figure 3 below provides a high-level depiction of how TAK provides a robust COP to enhance communications and disaster response efforts when time critical decisions must be made. More information can be found here: https://tak.gov/solutions.html

Figure 3. Illustration of TAK System.



7. PARTICIPANTS AND ROLES

Table 5 provides a list of the partners associated with the A62 live event and their roles.

Table 5. KSU Flight Event Partners.

Partner	Roles
KSU	Mission Commander, Visual Observers (VOs), Data Collector, Technology Support, A62/State of KS Lessons Learned Evaluators
MIRE	Technology Integration and Live Support, A62/State of KS Lessons Learned Evaluators

KDOT	Remote Incident Command, A62/State of KS Lessons Learned Evaluators
Local Law Enforcement	Incident Commander, Incident Commander Liaison, Site lead, Emergency Response
Local EMS	Emergency Response

8. SCHEDULING

A nominal schedule for each flight days is provided in Table 6. The Kansas State Fair is scheduled for **9/6/24 – 9/15/24**. Flight will only be conducted on the dates when the highest congestion of people is expected.

Flight Days

- 9/6/24
- 9/7/24
- 9/8/24
- 9/9/24
- 9/13/24
- 9/14/24

Table 6. Nominal Flight Schedule.

Start	End	Schedule
1000	1000	KSU Team Meets at Lab
1000	1030	KSU Conducts Pre-Deployment Checks of Equipment
1030	1130	KSU Travels to Hutchinson, Kansas
1130	1200	Arrival, Check-In, and Briefing
1200	1300	Equipment Setup and Testing
1300	0100	Gates Open to Public/Surveillance Begins/Lessons Learned

9. DATA MANAGEMENT

Data will be collected and compiled in a variety of locations during the live event. Each flight team will be responsible for managing their UAS data in the field. Local SD cards and live recording via the COP will both be utilized. All data will be collected at the end of the event day.

9.1.1. UAS Video

Live streamed video of the venue will be collected by the KSU team using UAS. The live stream video will be sent to the COP for data integration. Once calls for assistance are communicated to the RPICs, the UAS will begin recording video to the local SD card, while the COP will record all activities.

9.1.2. Static Camera Video

MITRE will capture video from static cameras positioned around the venue. These cameras will record continuously to their local SD cards and send FMV to the COP for data integration. All static camera footage will be recorded at the COP.

9.1.3. Local and Remote COP

MITRE and KSU will oversee the COP interface and work with the Incident Commander Liaison as needed. All data collected by the COP will be recorded locally. This includes:

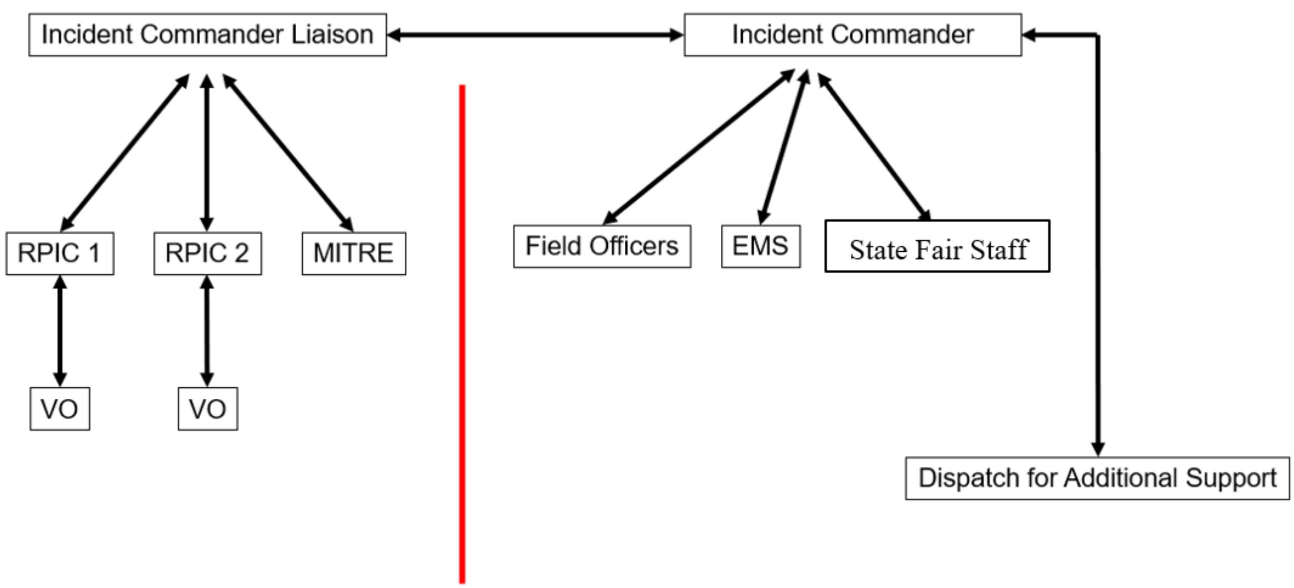
- UAS: FMV & telemetry data,
- Static Cameras: FMV
- End User Devices: telemetry data

Data will also be sent to a remote location for proof of concept using Starlink.

10. COMMUNICATION PLAN

Figure 4 below provides a high-level illustration of the communication structure:

Figure 4. Illustration of communication plan.



Appendix K. New Mexico State University Task 7 Report

A62 NMSU Mock Airplane Crash Emergency Response Test Report December 2024

December 11, 2024

NOTICE

LEGAL DISCLAIMER

TECHNICAL REPORT DOCUMENTATION PAGE

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16. Abstract
A two-day Mock Airplane Crash Emergency Response Test Functional Exercise was the culmination of this set of research flights. These efforts are in support of research assessing UAS response and support for multiple Natural and Anthropogenic disasters. The combined research teams implemented the products of previous related research including sets of UAS, support functions, and products for each type of disaster. A defined set of expected operational elements was outlined for an Airplane Crash Response and included previously defined UAS, functions, LiDAR, Thermal, and EO sensors, and products with a flow down from this previous work. The goal here is to exercise all of the elements during a full mock event exercise and to capture any specific and general cautions and improvements to the support. Mission plans were prepared in advance and the Test Plans and Test Cards were provided to the FAA for review and approval before the operations. This report details the execution, data, and lessons learned from the Mock Airplane Crash Emergency Response Test Exercise. The Mock Crash Test was executed as planned with 18 UAS flights over the two testing days from November 12 to 13, 2024 on an NMSU owned plot of land on College Ranch, New Mexico which is located approximately 14.84NM on a heading of 18 deg from the Las Cruces airport. The location was coordinated with the College Ranch caretaker personnel. The main foci for the testing derived from the test objectives were to 1) test all of the flight systems, sensors, equipment, and procedures in an actual mission scenario; 2) collect lessons learned; and 3) assess post processing of the data products. The missions completed all of the elements required. Desired data products were produced including the production of composite Electro Optical, thermal/multi-spec, and LiDAR maps before and after the wreckage cleanup. A Fixed Wing/VTOL with EO/Multispec/LiDAR and A free-flight multi-copter with a LiDAR sensor, and several small multi-copters with the ability to capture images and video in EO and IR, were flown during the event. With the small UAS, the operator was able to direct a first responder on the ground to the crash site and ultimately to the survivor using either EO or IR cameras. Lessons learned focused on equipment, flight operations, standardized communication during search flights between the Pilot and the Search personnel, and the post-accident mapping and some system related limitations to the LiDAR and Multispec products. All of the primary and secondary objectives as outlined before the missions were met in this Mock Airplane Crash Emergency Response exercise.

17. Key Words
Test Report
Plane Crash
Emergency Response
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LiDAR

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TABLE OF ACRONYMS

Acronym	Meaning
AGL	Above Ground Level
ASSURE	Alliance for System Safety of UAS Through Research Excellence
DJI	Da-Jiang Innovations
EO	Electro-Optical
FAA	Federal Aviation Administration
FTS	Flight Test Site
LiDAR	Light Detection and Ranging
NMSU	New Mexico State University
UAS	Uncrewed Aircraft System
UASFTS	UAS Flight Test Site
UTC	Coordinated Universal Time

EXECUTIVE SUMMARY

The ASSURE A62 research effort, "Disaster Preparedness and Emergency Response Phase III," was structured to provide insight into the safe integration of Unmanned Aircraft Systems (UAS) into disaster preparedness and emergency response areas. The research explored the use of UAS in providing effective and efficient responses to different natural and human-made disasters and emergencies. Culminating efforts for this work centered on exercises and mock events. This report details one of these events, a Mock Airplane Crash Emergency Response Test Functional Exercise. This two-day event was planned over six months with flight and system testing and multi-personnel coordination. The New Mexico State University (NMSU) team conducted various system tests and equipment preparations before the actual Mock Airplane Crash Emergency Response Test. All of these events were designed to ensure all equipment, procedures, and coordination were ready for the Mock Crash event. The goal of this test was to fully exercise all of the defined elements required in this event demonstration and to capture any specific and general cautions and improvements to the support. The main foci derived from the test objectives were to 1) exercise the flight systems, sensors, equipment, and procedures in the actual mission scenario; 2) collect lessons learned; and 3) assess post-processing of the data products.

The Mock Airplane Crash Emergency Response Test was executed as planned as detailed in the Federal Aviation Administration (FAA) approved Test Plan and Test Cards. 19 UAS flights were conducted over the two testing days on November 12 and 13, 2024 located on a plot of land owned by NMSU, at College Ranch, New Mexico. The location was coordinated with College Ranch management. The UAS flights were conducted by NMSU, with additional support from personnel with Police, Fire, and Search and Rescue experience. The initial flights included many Electro Optical (EO) and thermal search flights with a simulated survivor and hazard. The secondary flights were completed with multi-spec, EO, and Light Detection and Ranging (LiDAR) for mapping the crash before and after the wreckage was removed. Pilots were given a general area to perform a search, and it was up to them to find the survivor (live volunteer) somewhere in the area of the aircraft debris using UAS that could be flown manually to look at desired locations with thermal or EO cameras and for spot checks. One of the small multi-copters was used to capture a quick map for searcher use that was available quickly on site.

The 19 different flights covered all of the desired muscle movements and system checks. Detailed EO, Multispec, and LiDAR maps from before and after the crash debris removal were used to assess their usefulness in detecting crash debris and crash dynamics and to support a crash investigation. Detailed images of the search photos clearly show the quality and value of these tools. The ability of the UAS operator to guide the support team to specific overflight locations to see what was going on in real time was clearly demonstrated. The operator directed real time visuals of the event allowed for the assessment of the progress of the search, live survivor location, and identification of hazards on the crash site. The ability of the UAS to quickly locate a potential survivor and to direct the rescue personnel safely and quickly significantly reduces the time necessary to locate survivors in rough terrain. It also proved useful in assisting the searcher/rescue personnel in avoiding potential hazards. Lessons learned focused on system/flight products, flight limitations near hills and rock, and the required time to post-process composite images. All of the primary and secondary objectives as outlined before the mission were met in this exercise.

1 INTRODUCTION

This test report addresses A62 A11L.UAS.68: Disaster Preparedness and Emergency Response Phase III, Task 7 which is focused on "UAS Flight Testing Events and Scenarios." The main element is to "conduct mock (or real) UAS flights at UAS Testing Sites to illustrate the use of UAS during or after different types of disasters and emergencies." A62 Task 3 identified over 55 potential new use cases (12 Natural Disasters, 23 Anthropogenic Disasters, 3 Disaster Support Responses, and 3 Other Response Operations) from which one was selected for the test event. The "Airplane Crash" mock event was selected. Details on the participants, locations, and test cards to be flown by New Mexico State University (NMSU) Unmanned Aircraft Systems Flight Test Site (UASFTS) test are identified within this test report.

There is one test event covered in this test report. The event took place over two days. The approach was for the NMSU to perform a simulated search/rescue operation followed by an after-accident investigation using UAS mapping capability along with post-wreckage removal surveys. Additional "Rescue/Search" personnel with police, fire, and search and rescue experience were on site as well. The goal was to exercise all the elements required to capture any specific and general cautions and improvements. This report details the execution, data, and lessons learned from the Mock Airplane Crash Emergency Response Test.

2 TASKS

A62 involves numerous tasks associated with Disaster Preparedness and Emergency Response. This research will provide insight into the safe integration of UAS into the disaster preparedness and emergency response areas. The focus of testing is mainly on conducting Mock Event Demonstrations and gathering lessons learned from using UAS during these events. This report is part of A62, Task 7, Other, Mock Event Demonstration. It describes a Mock Airplane Crash Emergency Response test conducted in early November 12th and 13th, 2024 by New Mexico State University. As a product of this testing, there are several lessons learned that feed into Task 7.

3 TEST PLANNING

3.1 Test Plan and Test Cards

The Test Plan ("A62_Task 7_NMSU_Airplane Crash Test Plan") and Test Cards ("A62_Task 7_NMSU_Airplane Crash Test Cards") were prepared and provided to the Federal Aviation Administration (FAA) for review. The Test Plan covered the background test architecture, aircraft, sensors, flight locations, participant roles, schedule, data management, and communications plan. The Test Cards for each aircraft detail the platform used, sensor(s), altitudes, speed, location, supporting technology, and the specific flight script from preflight check, through flight, and post-flight. As with other tests, the format and content of these documents have evolved through multiple iterations in submissions to the FAA through different ASSURE flight test support elements. For reference, the Test Plan is attached as Appendix A and the Test Cards are attached as Appendix B, and the Site Survey is attached as Appendix C.

3.2 Test Objectives

A62 Task 3 identified over 55 potential new use cases (12 Natural Disasters, 23 Anthropogenic Disasters, 3 Disaster Support Responses, and 2 Other Response Operations) from which one, the "Airplane Crash" mock event, was selected to conduct a mock functional exercise.

UAS types, sensors, and needs required to support a search, and before and after mapping, were previously detailed to the FAA for other similar or proxy events in the A28 reports and multiple subsequent Technical Interchange Meetings with the FAA. The continuity from this previous work and the description of the Mission Procedures/Approach are documented in the Test Plan. This outlines the required UAS and associated sensors needed to support the end goals of a Mock Airplane Crash exercise. The various desired support functions are outlined and the approaches to accomplish the assigned elements are detailed.

The goal was to capture any specific and general cautions and improvements to the support. The main foci derived from the test objectives were to 1) exercise the flight systems, sensors, equipment, and procedures in the actual mission scenario; 2) collect lessons learned; and 3) assess post-processing of the data products. The mission employed all of the elements required to support this Mock Airplane Crash test functional exercise. The primary and secondary test objectives for the Mock Airplane Crash test are detailed as follows.

Mock Airplane Crash Test

The primary test objectives are:

1. Assess the usability, benefits, and drawbacks of UAS and sensors for a specific disaster, recovery, and response operation.
2. Utilize visual and thermal sensors to identify the crash location.
3. Utilize visual and thermal sensors to identify and locate survivors and hazards.
4. Utilize sensor and imaging systems to map the area before it is disturbed beyond what is required for first response efforts.
5. Utilize sensor and imaging systems to map the area after for post-remediation assessment.
6. Provide guidance and lessons learned from flight operations.

Secondary test objectives are:

1. Assess the data products and quality/resolution of the produced composite images.
2. Assess positioning and other safety and performance metrics.

3.3 Test Personnel

The NMSU UAS Flight Test Site (FTS) personnel performed all of the preparation and flight operations with the addition of three additional part-time personnel who have experience in search and rescue operations and emergency response.

Table 1 provides a list of the partners associated with the A62 NMSU flight testing event.

Table 1. NMSU UASFTS ASSURE A62 Event 1 Test Flight Partners.

Partner	Roles

NMSU UAS Test Site	Flight Test Director, Technology Provider, Remote Pilot In Control, Mission Commander, Visual Observer, Project Coordination, Data Collector, First Responders

3.4 Test Aircraft

The NMSU UASFTS provided all the aircraft and sensors for these flight operations. The general functions of the aircraft and sensors as determined in previous A28 and A52 research are to 1) provide search capability with EO or thermal sensors; 2) mapping with LiDAR, EO visible and visible near infrared sensors; and 3) operator directed "spot viewing" with EO visible and/or thermal infrared sensors. The combination of mapping before and after and viewing specific locations during an operation provides the team coverage of a search mission. The aircraft and functions for each are detailed in the Test Plan and not repeated here. For reference, the listing of the aircraft used includes the following:

- Skydio X2E with EO camera in manual flight for search and identify.
- Teledyne SIRAS with Thermal and EO camera (Thermal is what was used for this test). UAS was flown manually with a pilot-controlled camera for search and identify.
- DJI Matrice 30 (M30) Multi-Copter – manually flown spot viewing with EO for search and identify.
- Skydio 2 - Programmed flight for rapid map creation with an EO camera.
- Quantum Trinity Pro – mapping with LiDAR, EO, and multi-spec.
- X6 Multi-Copter – mapping with LiDAR.

3.5 Test Location and Airplane Proxy

The Mock Crash Site location was near rugged hills at College Ranch, New Mexico, located to the northeast of Las Cruces, New Mexico as shown in Figure 1. College Ranch, a ~100 mi^2 area is a research area owned by NMSU and is an excellent location for performing various UAS testing. It is a relatively short distance from NMSU Physical Science Laboratory (Las Cruces) and provides gated access to an isolated area with little to no population and few structures.

The area is desert terrain with scrub and cactus which becomes very rocky as you approach the hills where the fuselage, wings, and tails of a large decommissioned Aerostar UAS were placed. Aircraft parts were placed in a manner that would roughly simulate a small onboard piloted aircraft wreckage site.

Figure 2 shows the launch location simulating a search operation setup, and the wreckage site located at the base of a rocky hill with boulders and large Yucca plants. The search area was relatively small encompassing approximately 0.64 acres. Assumptions were made that in the case of a small aircraft crash, there would be location information provided by means of an Emergency Locator Transmitter to give an approximate location. Visual Observers with radio communications were able to work out of the simulated search basecamp to ensure flight safety. The staging/launch locations were flown out of the same base camp. The launch area is located in the upper right side of the figure. There was no practice day for this test. Operations were scheduled to occur on Tuesday, November 12, 2024, with Wednesday 13, 2024, as a backup or continuation day if needed.

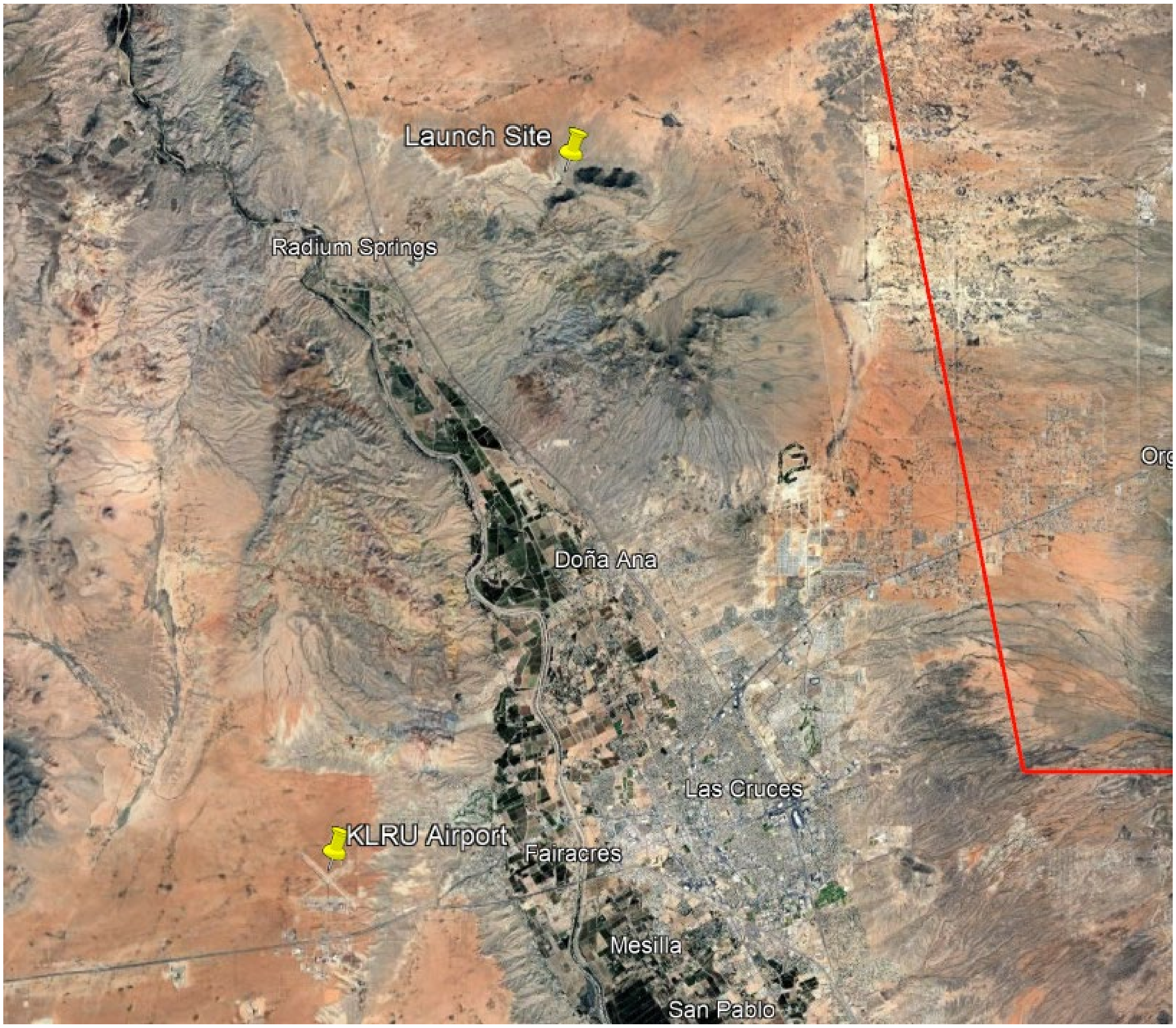

Figure 1. Search Launch location in relation to Las Cruces and airport.

Figure 2. Launch location and simulated wreckage site next to rocky hill.

The team set up and operated out of one location. Visibility from the ground was only limited by the hills located southeast and at the simulated crash site; otherwise, there was 20-mile visibility from the ground.

The Aircraft Proxy was an un-airworthy Aerostar airframe that consisted of the main, left- and right-wing panels (9 ft 5 in each), two tail booms (7 ft long) with rudders attached and the main fuselage (approximately 8 ft long).

3.6 Test Dates and Schedule

Nominal daily schedules for each set of testing were as shown in the Test Plan. The planning required one day on-site at a minimum to do the search flights and the post-cleanup/mapping flights. A second day was planned in the event there was a delay (weather for example) on the first day of tests. The research team implemented the products of previous related research and testing including sets of UAS, support functions, and products for this disaster. For this test, there were defined sets of expected operational elements outlined before the search and mapping flights. The first day of the flight window was nominally set as the wreckage setup, search, and guidance for ground rescue personnel on each UAS, and for post clean-up mapping. The second day was utilized to fly anything that was not able to fly the first day. These were started with transport to the flight location, pre-flight safety briefing, setup, preps, flights, post-flight briefing, collection of any lessons learned, and any tear down required.

3.7 Test Conditions

Weather conditions for flight tests conformed to Part 107 requirements (e-CFR 2024) since the aircraft and flights were operated under Part 107. No notable challenges regarding electromagnetic interference were identified before or during testing. It was noted during the testing, which ranged from 40°F to 70°F, that the equipment, systems, and aircraft performed as expected. Altitudes ranged from 100 ft relative to the takeoff point up to 300 ft above the takeoff point. Winds were a factor later in the day during the first testing day which contributed to the Teledyne SIRAS not flying until day two (it is limited to 22 mph to maintain position). Winds at the surface ranged from 10 mph up to 15 mph and at 300 ft above the takeoff point the winds were between 25 and 27 mph.

3.8 Test Cards

The test plan outlined several different UAS, sensors, and flight profiles. These are further broken down into detail in the Test Cards presented in Appendix B. The functions for the flights are search and pre/post mapping (multiple aircraft). The details by aircraft are repeated here:

- Skydio X2E with EO
- Teledyne SIRAS with EO/Infrared for on call response
- DJI Matrice 30 with EO and rapid mapping
- Skydio 2 with EO for rapid mapping
- Trinity EO Mapping
- Trinity LiDAR Mapping UAS (Qube240)
- Trinity Mapping UAS (Altum-PT Multi-Spec)
- NMSU X6 with LiDAR

3.9 Data Collection and Management

3.9.1 Metadata

Metadata regarding the relevant test card and time of test for each encounter were recorded using a form like that illustrated in Figure 3. In addition, notes regarding any other relevant information were collected in the margins of the form shown in Figure 3. Both hard copy and electronic copies of this form were used with hand recordings transposed to the electronic form. Metadata were also collected by various participants in the form of hand-written notes, emailed notes/comments/lessons learned, and photographs. These metadata are very helpful in developing/maintaining a high-level picture of the overall test campaign.

- Date
- Flt/Test Card #
- Location
- Data Recorder
- Flight Type
    - Met Flight
    - Check Flight
    - Scenario
    - Calibration

    - Muscle Movement
    - Cancelled
- Team
    - NMSU
- Flt Objective
    - Search
    - Rescue Mapping
    - Post Crash Investigation Mapping
- UAV/Sensor
    - Trinity Pro (Multi)
    - Trinity Pro (EO)
    - Trinity Pro (LiDAR)
    - X6 (LiDAR)
    - Skydio 2 (EO)
    - Skydio X2E (EO)
    - Teledyne (IR)
    - DJI M30 (EO)
- Pilot
    - J. Millette
    - J. Fisher
    - K. Common
    - AJ. Parra
    - J. Angel
- Launch Area Visual Observer – various
- Alt (Ft)
- Launch Time
- Land Time
- Duration
- Notes

Date:			Location:						Data Recorder:		
Test Card #	Team	Flt Objective	UAV/Sensor	Pilot	Launch Area VO	Remote VO	Alt	Launch Time	Land Time	Flt Time	Notes

Figure 3. Form used for metadata collection.

3.9.2 Aircraft Position Truth Data

The primary method of aircraft position truth data was the onboard flight data recording. Each aircraft records data in a slightly different format, and all of the flight data is recorded and then downloaded post-flight. All of the UAS were compliant for the flights and included remote identification.

3.9.3 Additional Data Sets

Additional data were collected during the test period. These include:

- Images: Collected by participants using their cell phones.
- Screenshots: A few screenshots of display systems were also collected.

4 FLIGHT DATA COLLECTION

In many research efforts, the plotted flight data is a key product. For these tests, the produced composite images, flight images, and video are the main products of interest with the actual flight paths as a secondary product. Flight plots are stored but are not reproduced here. The data collected for each flight generally include 26 different logged elements, parameters, or data. Some are related to housekeeping and system status. The key parameters collected for these analyses include the following:

UTC DATE
UTC TIME
LOCAL DATE
LOCAL TIME
LATITUDE (including N/S)
LONGITUDE (including E/W)
HEIGHT (m)
SPEED (km/h)
HEADING
ELEVATION
AZIMUTH
DISTANCE (m)

5 MOCK AIRPLANE CRASH EMERGENCY RESPONSE RESULTS

The Mock Airplane Crash Emergency Response Test was executed as planned and detailed in the FAA approved Test Plan and Test Cards with 19 UAS flights over the two testing days. The flights included search and recovery flights via multiple UAS with both EO and thermal cameras, and mapping flights with a free-flight multi-copter with a LiDAR sensor, and a fixed wing vertical take-off and landing using three different payloads (EO, Multispec, and LiDAR) for mapping. Detailed breakdowns of the day-by-day operations, images/video captured, and produced maps/data products are included in this full Mock Airplane Crash Emergency Response Test Report. In advance of the flight operations week, the NMSU truck was loaded with the simulated airplane crash wreckage, UAS, and mapping aircraft. This included all the UAS and support equipment needed for the operations. The NMSU team arrived on site at College Ranch at 0730. From there, equipment and aircraft along with crews were transferred to 4-wheel drive vehicles to travel to the actual test site. The road was a two-track and was representative of the potential operational requirements for remote survivor/accident search and recovery locations. Short day-by-day summaries of the operations, flights, and examples of the products are presented below.

5.1 Tuesday, Nov. 12, 2024

Tuesday was spent traveling to College Ranch where the NMSU team parked the 2-wheel drive truck that was loaded with the Aerostar fuselage parts (simulated crashed aircraft) and all the UAS and support equipment. Once there, equipment and personnel were transferred to two 4-wheel drive trucks that were used to get from College Ranch Headquarters to the launch (base camp) site shown in Figure 4. Once at the base camp, operations were set up for the various UAS (Figure 5). Minimal support equipment was required, and power was supplied by a small Honda generator and two Jackery portable power supplies. Once the base camp setup was complete, three personnel transported the aircraft wreckage to the proposed accident site as shown in Figure 7. One person was to remain at the Mock Airplane Crash site to simulate a potential survivor. Figure 7 shows the distribution of the wreckage and Survivor "Henry" for day one flights. Figure 8 is a view of the wreckage field, Figure 9 is a view from the Skydio X2E showing the mock wreckage, and Figure 10 is a view of the first responder driving to the wreckage site.

The UAS pilots were aware of the general area of the Mock Airplane Crash but were not given specific coordinates. The idea was to locate the center of the search area and to circle out from that location, to locate any survivors and determine the size of the wreckage field. Once the survivor was located, the idea was to use the drone to guide the "first responder" to the survivor and to avoid a hazard. In this case, the hazard was a small space heater to represent a heat source.

The Skydio X2E was flown first, its EO camera being used to perform a search of the Mock Crash area. There was a pilot and an additional person who communicated with the first responder via radio. The search area was at the base of a small rock-strewn hill (approximately 200 ft high). The flights started at 0839 while the sun was still behind the hills, casting a shadow over the search area which made it more difficult to detect a survivor with an EO camera. The wreckage was easily identified which helped narrow the search area. The wreckage and the survivor were both located in the early morning shadow at the base of the hill. The zoom on the Skydio was of average quality and clarity, making it more difficult to pick up the survivor in the shadow. It would take a second flight of the X2E after a battery swap to finally locate the survivor leaning against a large rock, partially masking their location. This was a realistic representation of a survivor seeking additional shelter while awaiting a rescue. Of note was a lack of ability to contact the survivor. They might be able to hear the drone and could reasonably expect it was a potential rescuer, but there is no external speaker or auxiliary lighting to potentially notify them of what is happening. Adding a speaker, or possibly adding the ability to drop a cell phone or handheld radio could be options to mediate this. This is an area that needs further development.

An additional factor in the search was the requirement to identify a potential hazard to both the search personnel and the survivor. A small heater was used to simulate a heat source or fire. Without a thermal feature, the only way to identify the hazard is by looking for a known shape. Figure 11 shows the sequence and how difficult it was to see the survivor leaning against a rock.

This scenario had an area that was smaller than might be encountered if the location was less well-defined. In that situation where a "first responder" may not have an easy time getting to the crash area, being able to identify coordinates would be necessary. Unfortunately, as the team discovered, not all systems readily provide that information. In the case of the Skydio, you have to switch your view to the map where it has an icon for the UAS and displays the Latitude and Longitude of the aircraft (not what the camera is looking at). In the case of the Teledyne, it will record the location of the aircraft, however you have to return to home and download the information from an SD card which is time-consuming. The better system proved to be the DJI Matrice which can use the laser range finder and will display the location in the camera view. It is also capable of showing the location that the camera is looking at using the Pin Point procedure.

The next UAS scheduled was the Teledyne SIRAS which was equipped with a thermal capability as well as EO. Unfortunately, there was a wind limitation of only 11 to 12 mph for hover, although this limitation was found to be an error. Winds were approximately 10 to 11 mph at the proposed time of take-off however winds in the vicinity of one hundred to two hundred feet Above Ground Level (AGL) were in the twenty-five to twenty-seven mph range. It was decided not to fly the Teledyne on this day.

Next to fly was the Matrice 30 with a wide zoom EO camera and a laser range finder. A different pilot was used as well as a different first responder. Neither of them had seen the wreckage site prior to this flight An additional person was used to relay communication between the pilot and the first responder via handheld radio, as in the first test with the Skydio X2E. The Survivor was moved to a different location from the first flight, requiring the pilot to search the area similar to the Skydio flight.

The camera on the Matrice was clearer and provided a better picture of the area to be observed, making it easier to identify objects. The pilot was able to identify the hazard (space heater) and give the location to the first responder so they could avoid the hazard. With the Matrice, the pilot was able to locate the survivor on the first flight. Winds during the flight were estimated at 25 to 28 mph near the top of the hill as stated previously. A second flight was performed to assess the ability of the Matrice to perform a quick mapping survey using the EO camera. The Matrice has a programming ability to fly a mapping mission quickly and process the map post-flight locally at the site. There were difficulties in setting parameters for mapping, attributed to the lack of experience with the system. The first mapping flight ended up running low on battery, so a second mapping flight was conducted after the Skydio 2 mapping mission was flown. The second mapping mission was flown without further delays or difficulties. Mapping examples are given later in this report.

The aforementioned Skydio 2 flight utilized the Skydio 2, equipped with the Sony IMX577 EO camera. This UAS could fly a mapping mission and was used to map the area of the Mock Crash to assess the usefulness of the mapping product. The pilot was made aware of the area to be mapped based on previous search flights. It was noted that the controller had issues preventing the operator from adjusting the location of the search area, which required resetting the controller. Part of the problem appeared to stem from direct sunlight on the screen, making it difficult to see. This flight occurred at 10:10 a.m., when the sun was higher on the horizon, further impacting screen visibility.

There were no flight or safety-related issues or concerns. A summary of the flights for the day is as follows:

- Flights: 13 total (2:38 flight time total)
    - Skydio X2E –1st search flight, (0:18 flight time total)
    - Skydio X2E – 2nd flight search (0:11 flight time total)
    - Teledyne SIRAS –0 flights (0:00 flight time total) Cancelled for winds.
    - Matrice 30 – 1 flight Search (0:18 flight time total)

- Matrice 30 – 2nd flight mapping (0:07 flight time total)
- Skydio 2– 1 flight mapping (0:06 flight time total)
- Matrice 30 –3rd flight mapping (0:07 flight time total)

Figure 4 shows various images of travel to the Mock Airplane Crash Emergency Response Test site and set up of the operations. Travel to the Mock Crash Site was representative of what might be required to get within a reasonable range for the UAS. The wreckage was distributed along the bottom of a hill and spread out in a manner that you might expect after a crash. The mock survivor placed themself in a location that was somewhat protected and increased the difficulty for the UAS pilot to locate them. Figure 5 is a view of the flight operations area where preflights were completed and UAS were prepared for flight operations. Two of the UAS used for the flight operations and mapping and mission support are shown in Figure 6. Figures 7 and 8 are photos after the team dispersed the representative aircraft wreckage. The same general placement was used on both days. Figure 9 shows what effect the shadow had on initial flights and how it would affect the pilot's ability to identify a survivor in those conditions. Figure 10 shows how the "first responder" traveled to the crash location, being guided by seeing where the drone was and by the pilot via radio. Figure 11 shows how difficult it can be to locate a survivor, especially with the shadow and their attempt to reach some sort of cover. Did you find Henry? He is leaning against a large rock at the bottom center of the photo on the right side of the rock. Figures 12 and 13 represent the "first responder looking for the survivor, being guided by the drone/communications with the pilot. Figures 14 through 18 show different views of the crash site from varying altitudes. Figures 19 and 20 show the significant difference in resolution between the DJI Matrice 30 (Figure 19) and the lower-quality Skydio (Figure 20) emphasized with a subsection of the orthomosaic. The intent of these maps was not to compare directly, but to visualize the difference of resolution that can be achieved when comparing default settings flown at the same altitude.

Operations followed previous protocols with no issues. Lessons learned were as follows: Communications between UAS operators and search personnel must be briefed before those search personnel begin their movement toward a crash site. The size of the viewing area of the controller screen and how bright it is can be a factor in how easy it is to find specific objects such as survivors or possible hazards. The larger screen of the Matrice controller is a better option than the smaller screen of the Skydio.

Mapping with the Skydio or the Matrice, using the EO camera, was quick (processing was completed on-site) and could be passed on to first responders for additional search purposes if required. It could also help identify additional hazards if they exist. A secondary use could be for post-accident investigation since it most closely represents the conditions immediately after the accident.

Figure 4. Various images of the area prepared before the Mock Crash Search.

Figure 5. Flight Operations (base camp) for search and rescue.

Figure 6. Various UAS used for the flight operations mapping and support.

Figure 7. Wreckage setup.

Figure 8. View of wreckage field.


Figure 9. Camera view from Skydio X2E of wreckage with morning shadow.

Figure 10. First Responder enroute to accident site.

Figure 11. Survivor located near rock and Yucca bottom of picture.

Figure 12. First Responder locating survivor with help from Skydio X2E.

Figure 13. First Responder locating survivor guided by Skydio X2E.

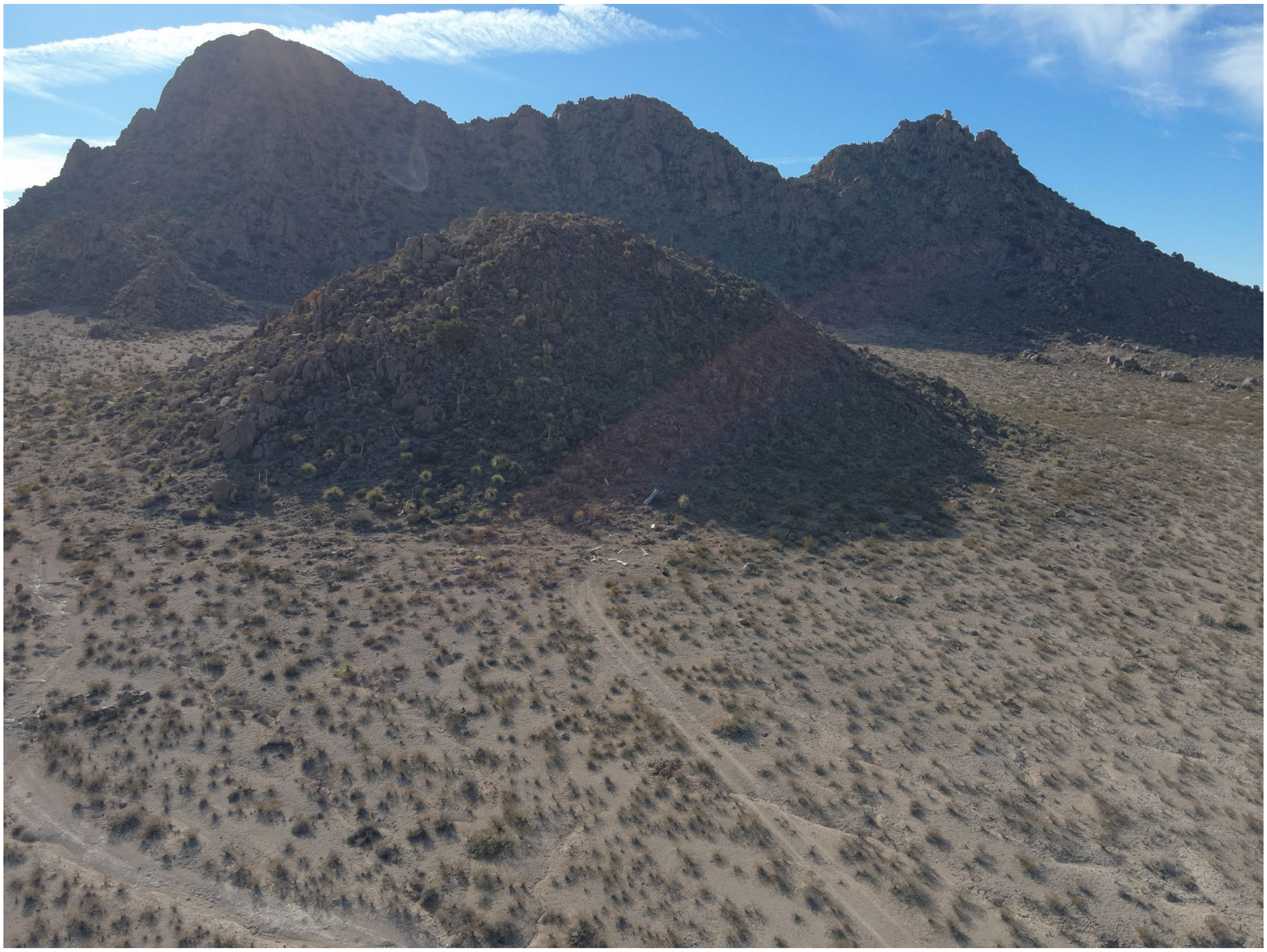

Figure 14. View of Wreckage from Matrice at 200 ft.

Figure 15. Overview of wreckage from Matrice.

Figure 16. Survivor located center picture.

Figure 17. DJI M30 Rapid Composite Map Overview.

Figure 18. Skydio 2 Rapid Composite Map Overview.

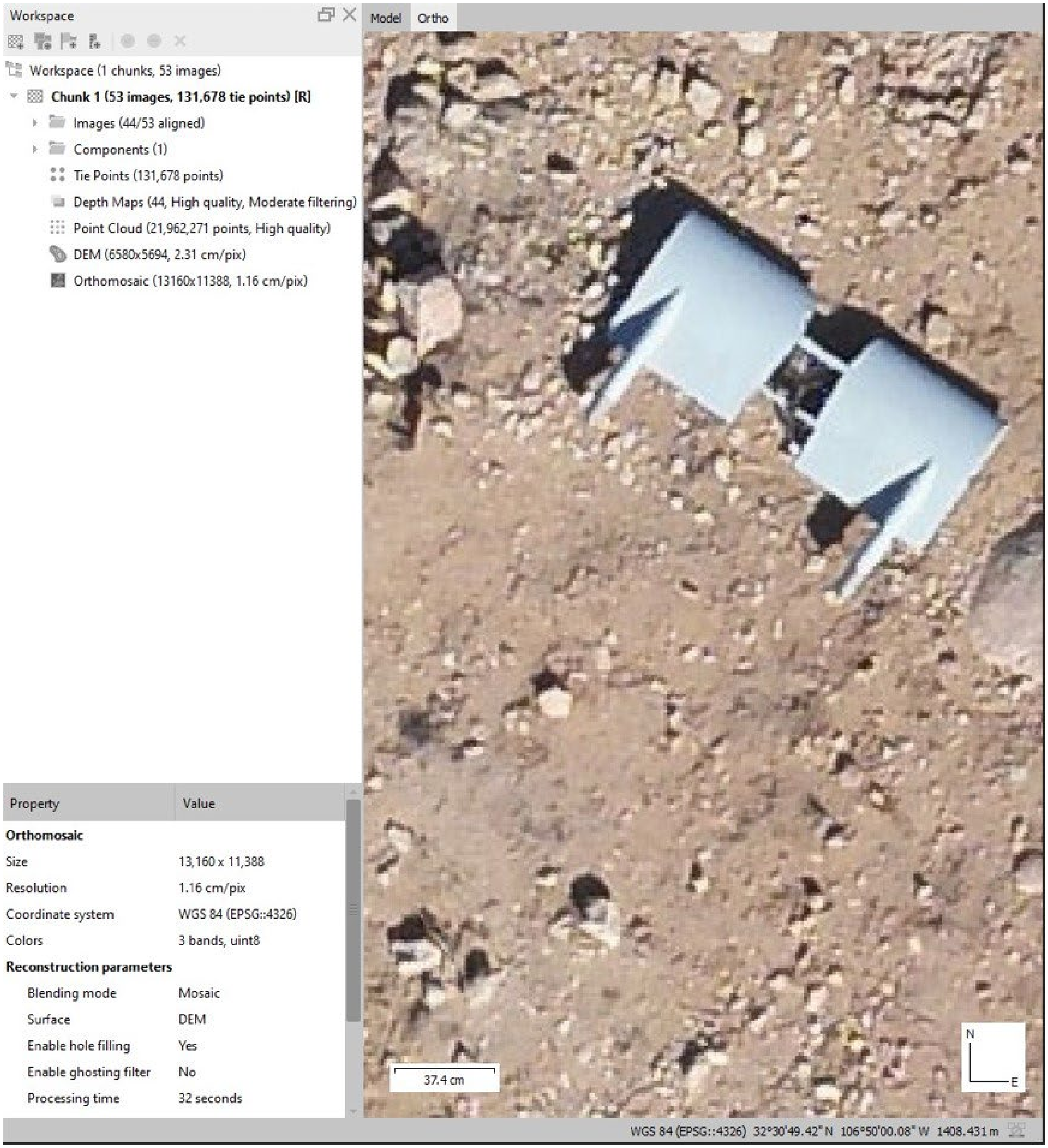

Figure 19. DJI M30 Map Detail Comparison.

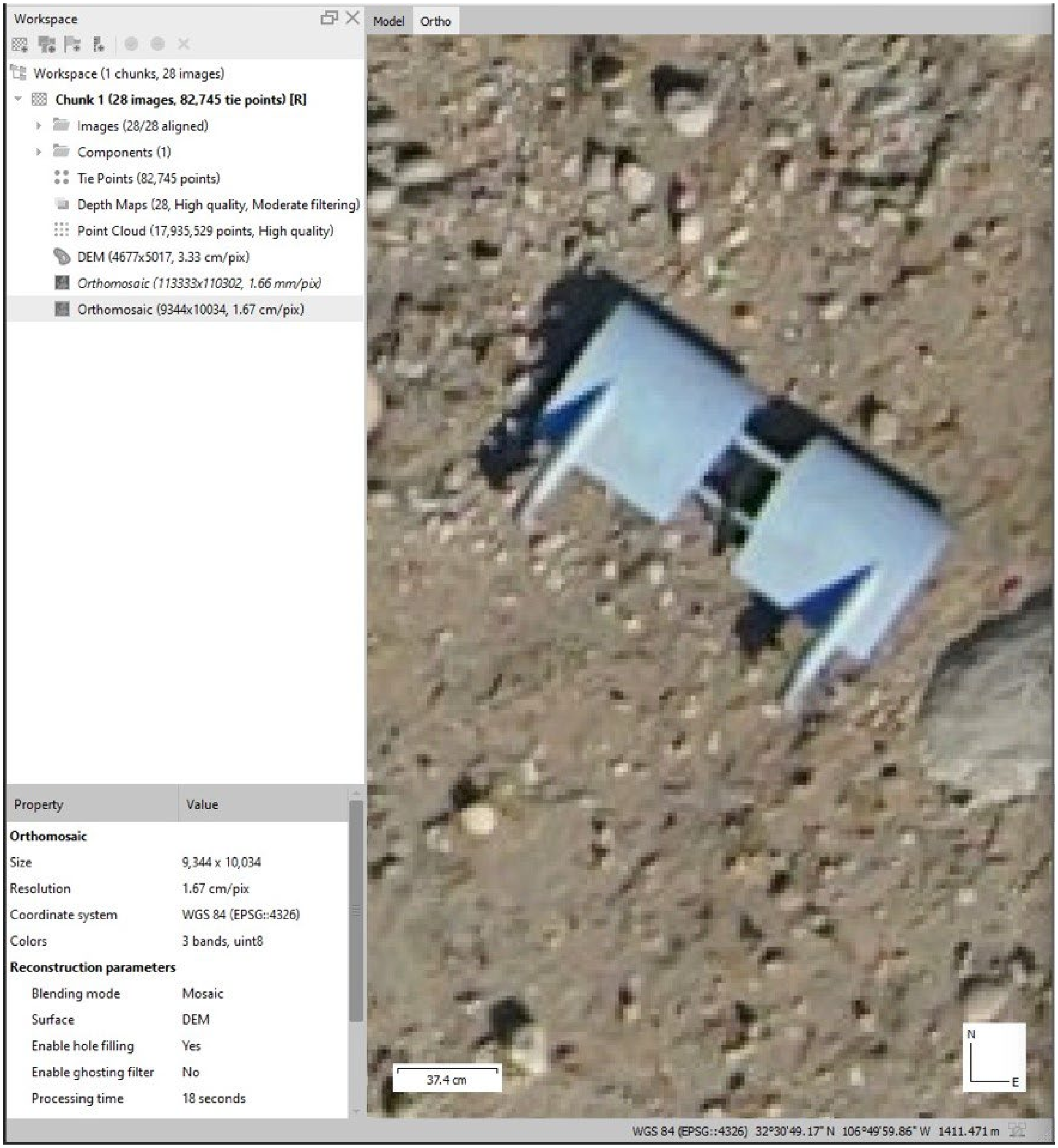

Figure 20. Skydio 2 Map Detail Comparison.

5.2 Wednesday, Nov. 13, 2024

Wednesday yielded lower winds allowing for flights with the Teledyne SIRAS, Trinity, and X6 aircraft. Additional NMSU personnel in the form of a retired Las Cruces Police Department officer joined as an additional simulated first responder. Flights were from the same location used on Tuesday. The team began by splitting into two groups to prepare the flight operation area and the mock crash site in a manner as similar as possible to the previous day. One person remained at the crash site to act as the survivor and activate the hazard in the form of a small propane heater to be identified by the pilot.

The Teledyne SIRAS was prepped for takeoff to conduct its first search and identify flight. Shortly after flight the pilot experienced degraded control of the aircraft and decided to abort the mission and safely land the aircraft. The pilot performed a compass calibration of the aircraft and experienced no further issues. During this time the survivor extinguished and restarted the propane heater to increase operational safety by minimizing the run time of the fire hazard. The aircraft was again launched to head towards the mock crash site and a first responder was dispatched shortly after launch, to head in the direction of the mock crash. During transit to the mock crash area, the pilot observed an altitude limitation of one hundred feet. This limitation was a carryover from previous operations in the form of a set altitude restriction in the controller. The pilot opted to continue the flight with this limitation in mind.

The pilot was able to identify the crash area and guide the first responder to the mock crash area. This system does not provide real time GPS location display, which is considered a drawback to its usability when supporting first responders. The survivor noted the radio calls on more than one occasion led the first responder in the wrong direction. The first responder also requested the pilot maneuver the aircraft to help them see its location relative to their own position. While the pilot was able to identify the hazard more quickly using the infrared camera, the limited field of view and altitude made it challenging to provide the responder with a precise relative location. The pilot identified the location of the survivor even though the aircraft location relative to the survivor was masked by local vegetation (Figures 21 and 23 are the Thermal views and Figure 22 was using the EO camera). The aircraft was maneuvered to bring the first responder into view as well and the pilot used a clock position method to guide the responder to the survivor. This concluded the Active Support portion of the test, and all personnel returned to the launch area.

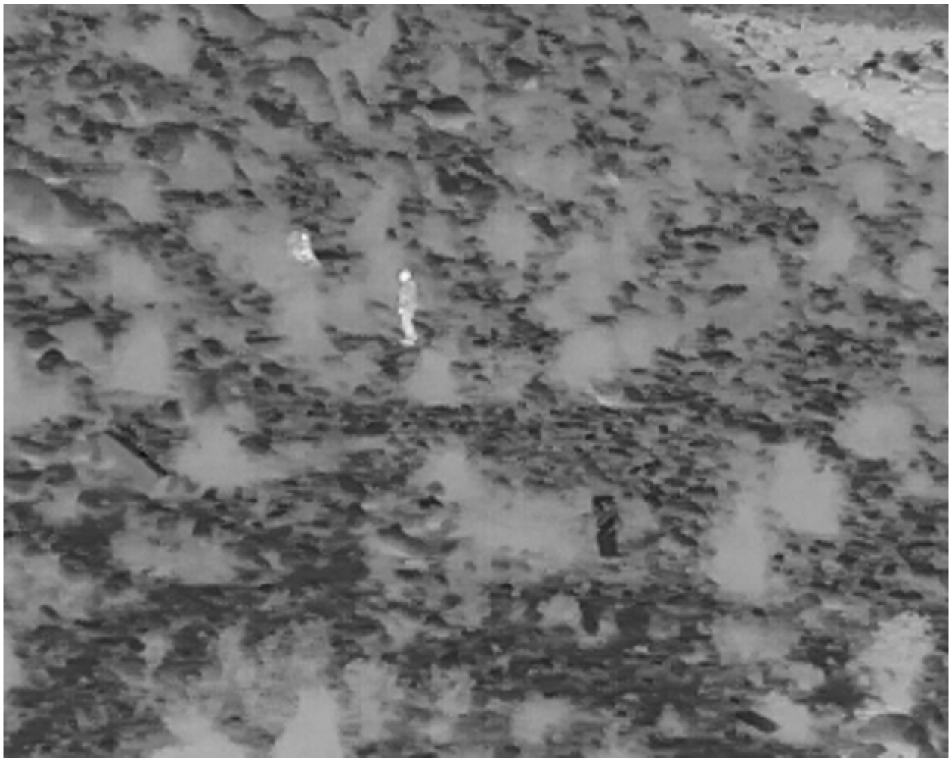

Figure 21. Teledyne SIRAS Thermal View of First Responder and Survivor.

Figure 22. Teledyne SIRAS EO View of First Responder and Survivor.

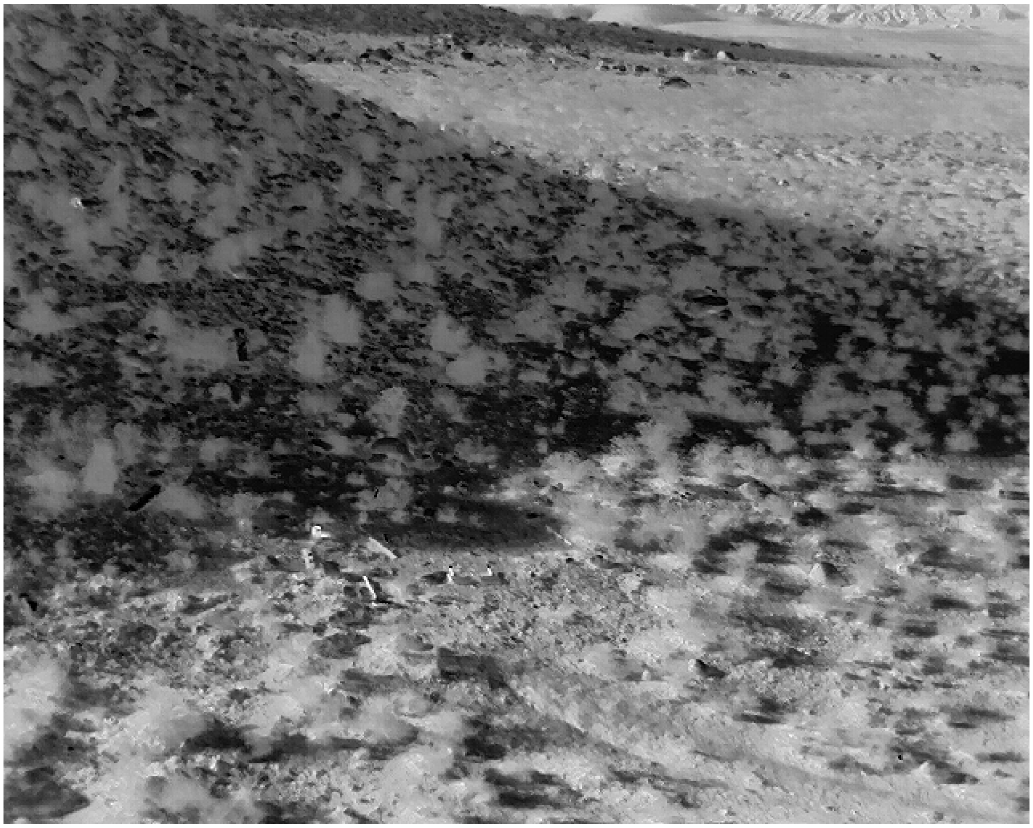

Figure 23. Teledyne SIRAS View of Hazard and Survivor.

While these operations took place, personnel prepped both the NMSU X-6 and the Trinity Pro to begin the Documenting and Investigation stage of this test with all mock crash parts remaining in place. The X-6 with LiDAR was the first flight to map the mock crash area for review during the investigation. When the aircraft was recovered it was identified by the external pilot that the camera used to colorize the LiDAR data was no longer shuttering. This issue required the flight to be repeated and initiated troubleshooting. During this time, the Trinity was launched to complete the first of three flights, with all mock crash parts remaining on the ground. During vertical takeoff, the Trinity displayed a "battery critical" warning, and the flight was aborted, safely descending back down to the ground. With the battery still showing more than sufficient charge the crew opted to swap the battery for later troubleshooting and the flight was reattempted with no issue. The Trinity payload was swapped to LiDAR and during the pre-flight the aircraft reported memory card full, the flight was aborted to allow the X-6 to fly. The X-6 was launched again to reattempt the LiDAR mapping with the same result of the camera shutter observed stopped on landing. The Trinity was launched to reattempt the LiDAR mission with no issues and the team proceeded to the multispectral mapping flight with no issues (Figures 24 through 27). Another flight was attempted with the X-6 with the same result of a camera failing to shutter on landing.

Twenty-three of the twenty-five crash parts were recovered leaving a metal plate and a junction box at the mock crash scene to simulate recovery of the aircraft after the crash. The X-6 was flown again with the shutter issue unresolved, allowing the team to capture the LiDAR data. The colorized X-6 LiDAR images utilized the EO images from the Trinity to complete the processing (Figures 28 and 29). The Trinity completed all three different sensor flights without issue. Figure

30 is an example of the EO camera on the Trinity with all parts and Figure 31 is with only two parts still in the mock crash area. Figure 32 shows a detailed view of the two remaining mock crash parts using the Trinity EO camera view. The team then recovered the remaining two parts from the mock crash site and verified all items were recovered against the crash parts inventory list.

Figures 33 and 34 show the results of developing the thermal view from the Trinity. Though it does show some detail, such as the roads leading to the mock crash site, you can see it would not be useful for determining the location of the debris from a crashed aircraft.

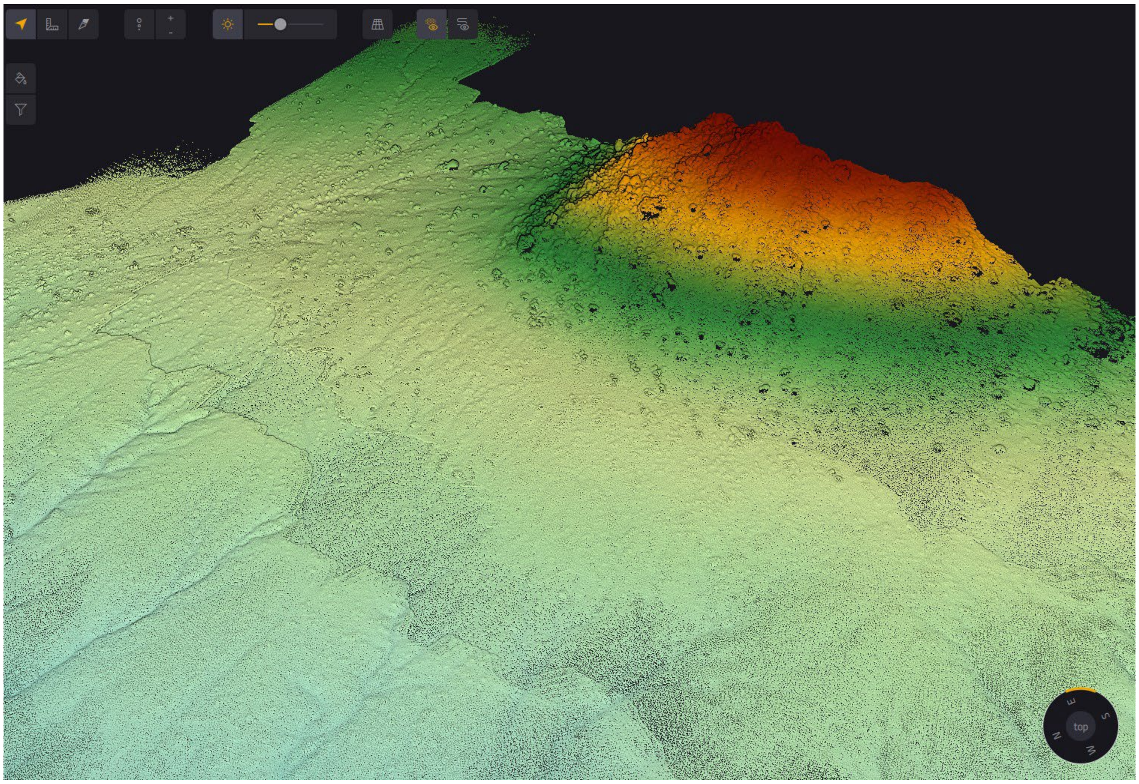

Figure 24. Trinity LiDAR Elevation with all mock crash parts.

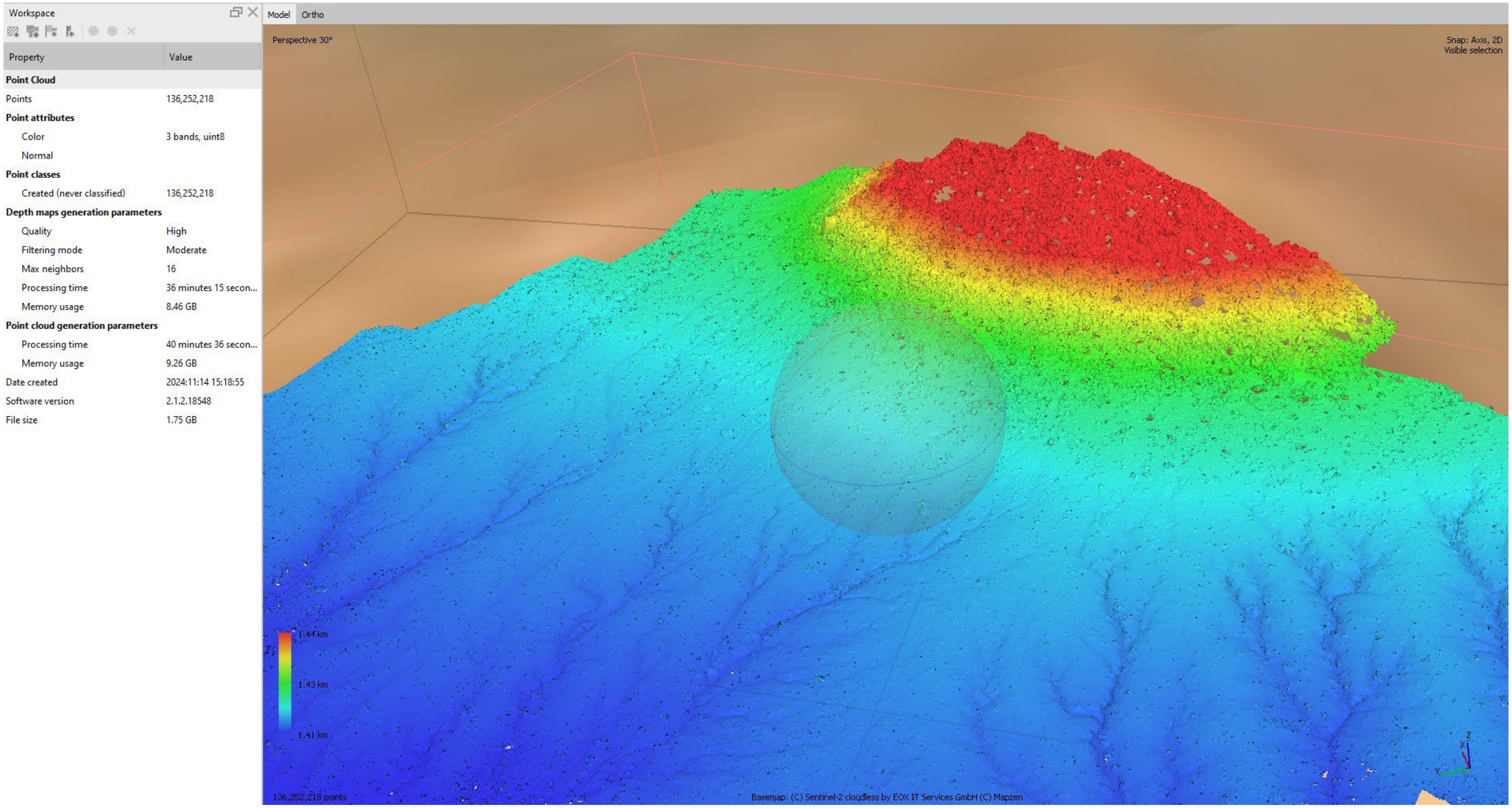

Figure 25. Trinity EO Elevation with all mock crash parts.

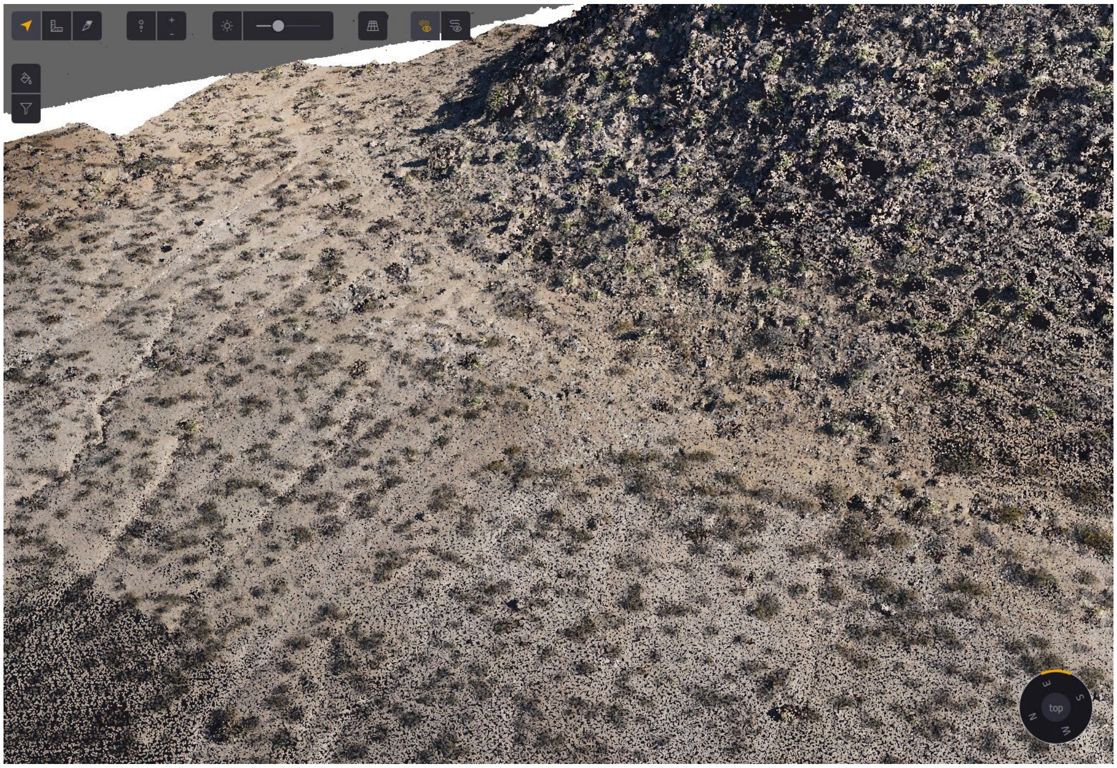
Figure 26. Trinity LiDAR colorized with all aircraft parts.


Figure 27. Trinity LiDAR colorized with two remaining mock crash parts.

Figure 28. X6 LiDAR colorized with all mock crash parts.

Figure 29. X6 LiDAR colorized with two remaining mock crash parts.

Figure 30. Trinity EO with all mock crash parts.

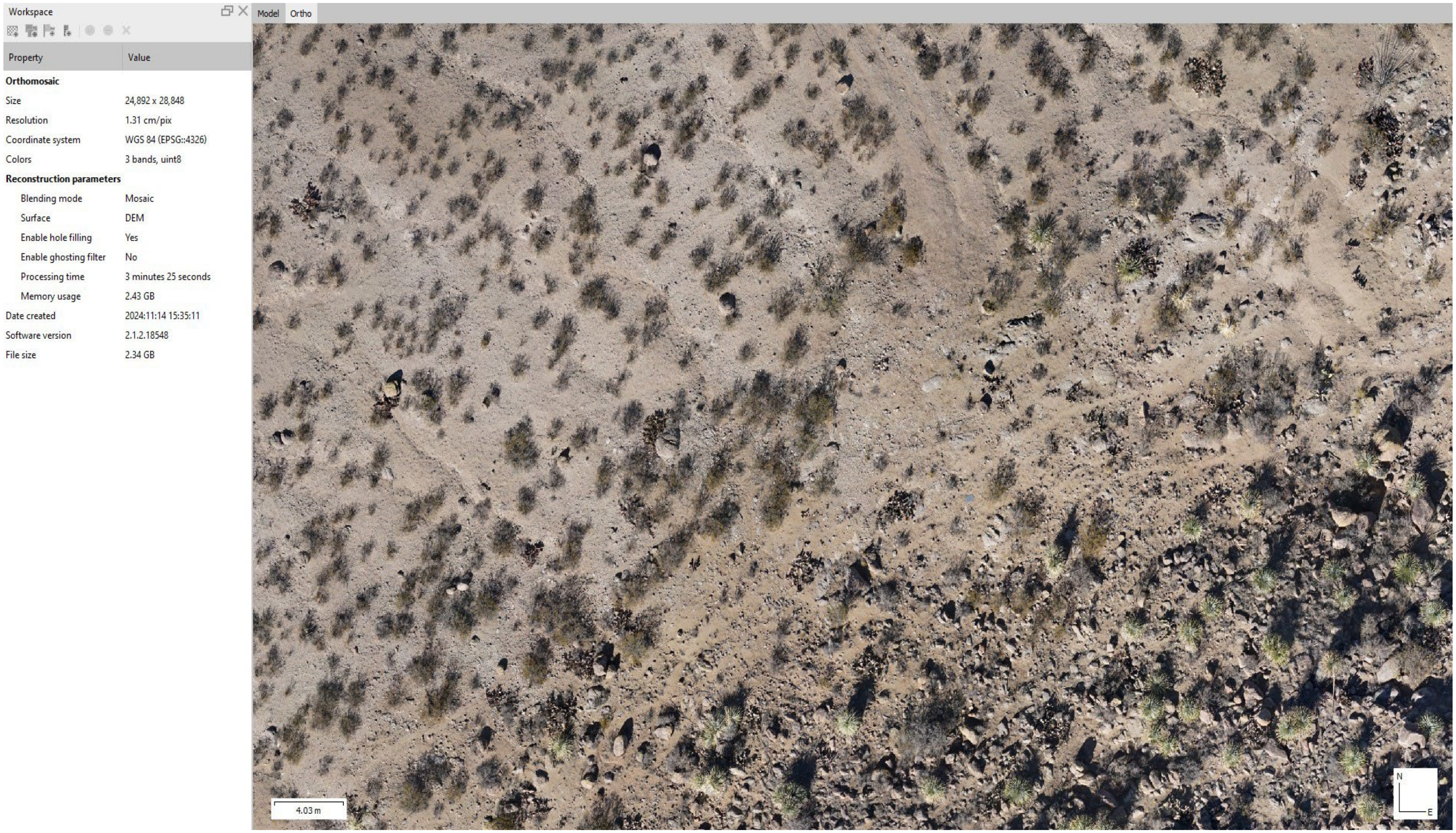

Figure 31. Trinity EO with two remaining mock crash parts.

Figure 32. Trinity EO detailed view with two remaining mock crash parts identified (red).

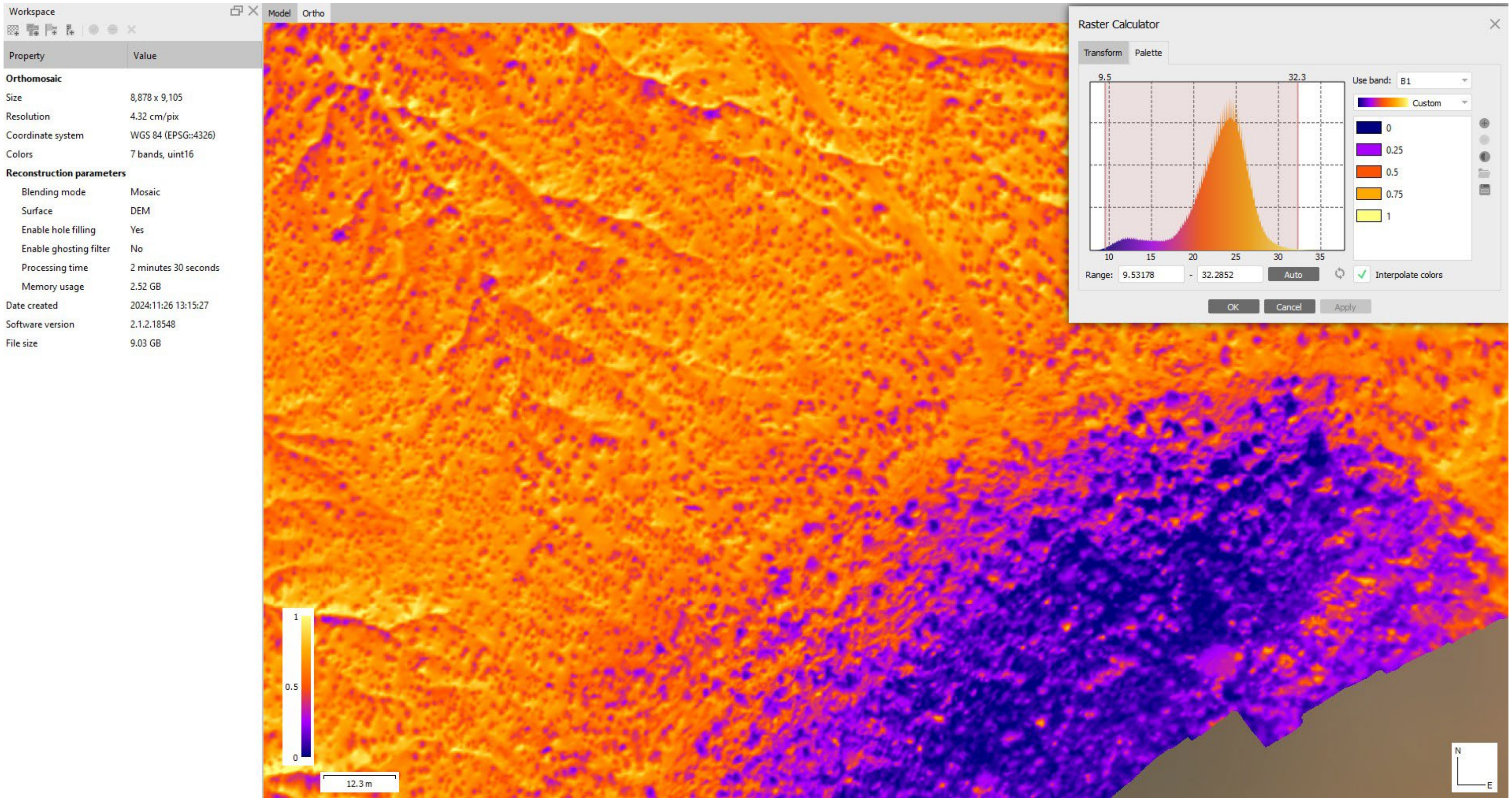

Figure 33. Trinity Thermal with all mock crash parts.

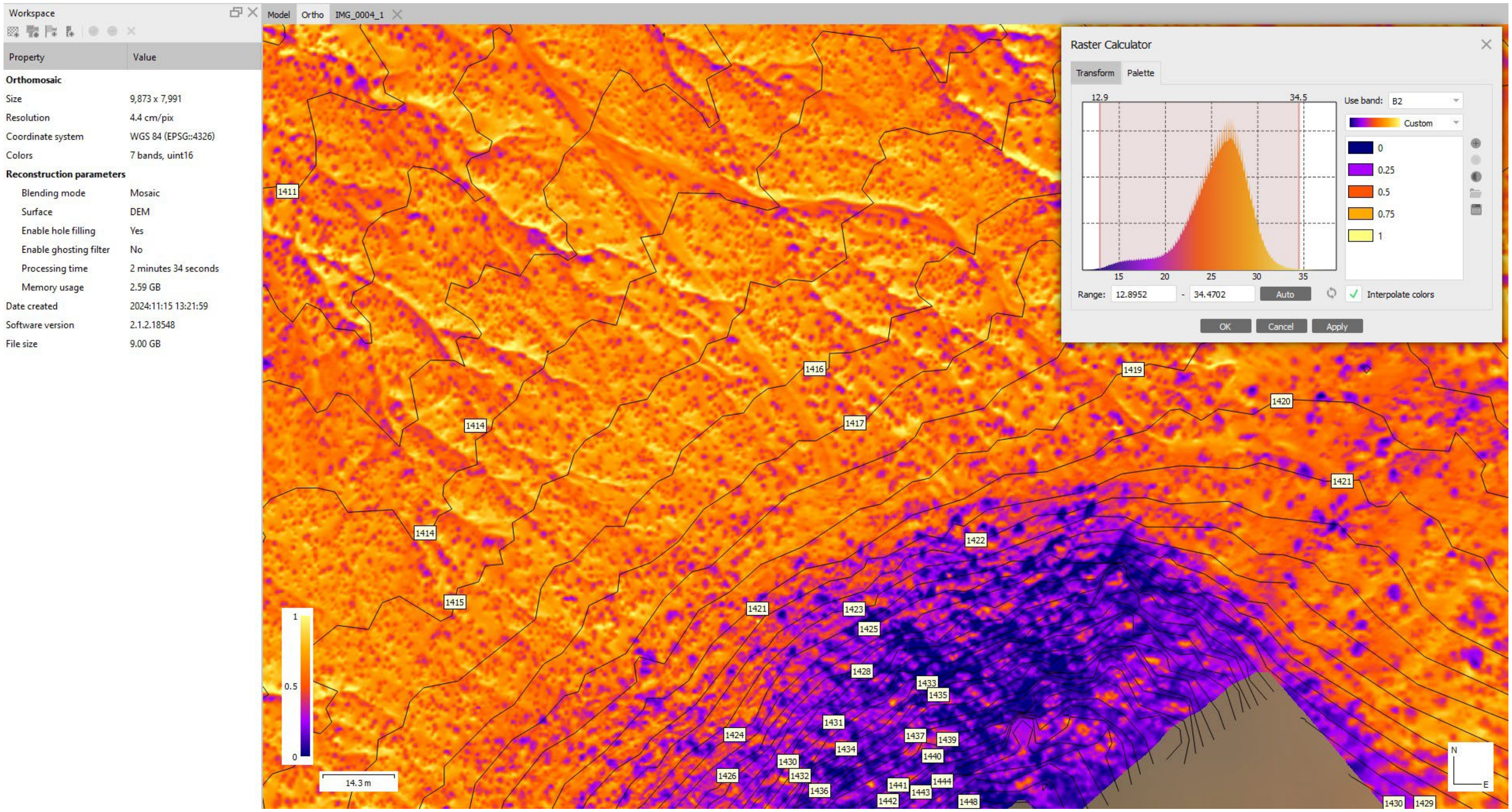

Figure 34. Trinity Thermal with two remaining mock crash parts.

Again, there were a few equipment performance challenges, but there were no flight or safety-related issues or concerns. A summary of the flights for the day is as follows:

- Flights: 13 total (1:36 flight time total)
  - Teledyne Siras – 2 flights (0:16 flight time total)
  - Trinity EO – 3 flights (0:15 flight time total)
  - Trinity LiDAR – 2 flights (0:16 flight time total)
  - Trinity Multi-spec – 2 flights (0:17 flight time total)
  - X-6 with LiDAR – 4 flights (0:32 flight time total)

All of the mapping flights require multiple images of data to be combined into composite images of the area. One EO composite image (Figure 29) stitched from the Trinity UAS captured images of the entire crash area with all parts remaining.

There were a few lessons learned that focused on operational items related to system limitations, and minor improvements, that are specific to the platforms utilized on this day. The Teledyne SIRAS pilot acknowledged that the operator's manual suggested a compass calibration after moving locations although the manual does not specify the distance of movement. Moving forward, NMSU will adjust the checklist to ensure any takeoff site movement will prompt a compass calibration even if the aircraft does not suggest this in the flight display. The wind limitation of the Teledyne SIRAS listed in the operator's manual was identified to be incorrect as stated by a Teledyne representative on the frequently asked questions page. This increased the wind limitations from twelve miles per hour to twenty-two miles per hour. The X-6 Sony camera failure was unrecoverable in the field and the NMSU team will work with the manufacturer to determine the cause of failure. This failure is a reminder that many of the systems utilized run on a single point of failure.

A summary of all of the flights over the two days A62 Mock Airplane Crash Flight Log and weather data is presented in Appendix D. This includes which pilot flew what drone for what purpose or flight objective. The pilots, visual observers, flight altitudes, launch time, landing time, flight duration, and any notes are recorded. Appendix E presents some additional images from the testing.

Additional Mock Airplane Crash Emergency Response Test Images are included in Appendix E. Figure 47 is a view of the Mock Crash Site with simulated debris. Figures 48 through 66 show the individual items that were used to represent the Mock Airplane debris. A list of these items with pictures is also included in the Test Plan as Appendix A to the Test Plan. Figure 67 shows the simulated hazard as a propane heater and tank to represent a heat source as a hazard. Figure 68 shows a view of the Matrice as it hovered in an almost overhead position to help locate the survivor. Figures 69 and 70 are additional views of the simulated wreckage/debris. The survivor, leaning against a Yuka, is partially hidden from view of the first responder in Figure 71. Figures 72 through 74 show additional views of the Thermal camera from the Teledyne. Figure 75 is a view of the hills in the vicinity of the mock crash site. It provides a good example of the effects of the shadow on the area. Figures 76 and 78 show the operations area and Figure 77 shows the display for the portable weather station used on site.

5.3 Lessons Learned Summary

All the fight missions were completed safely under Part 107 operations. There were no safety challenges or issues. There were a few minor equipment challenges that were encountered. All the items were captured in these lessons learned. There are always potential improvements to the processes and operations. Many lessons learned are germane to a team, a tweak to the procedures, or unique to a specific operation. NMSU teams captured these lessons learned or reinforced some of their best practices.

There were a few global lessons learned that are more applicable post-mission. The key ones are worth repeating here since some point toward bigger picture elements for future support of flight operations related to Airplane Crash Response. These key notes are broken down by aircraft or required support function.

- Mapping products consume time post-flight to produce rendering the EO, thermal, and LiDAR images and are generally not available immediately after a flight. Some processing and stitching time for the images can take many hours. Many of the Trinity maps are between 2.5 and 4.5 cm per pixel resolution and unfortunately, did not prove useful in identifying even the larger crash panels such as the wings or fuselage. The most useful of the Trinity maps is the EO mapping allowing the user to see a full picture of the mock crash area and zoom to parts for further identification.
- One of the UAS (Teledyne) had an issue with maintaining the desired heading which was attributed to not performing a calibration. It had been flown at the airport numerous times without issue, and the other UAS did not have a problem. It was determined this particular system requires a compass calibration every time it flies in a different location regardless of how close the last position was.
- Display of the UAS location in a coordinate format is not standardized or, in some cases, not available on the viewing screen without the UAS returning to the takeoff point (Teledyne). The Skydio 2 and Skydio X2E could not display the coordinates in the camera view, only if you switched to map view. The DJI Matrice was able to display coordinates if you used the laser range finder, otherwise it was not available. This coordinate directly indicated where the range finder was impacting the ground, not the position of the aircraft. It is very important to be able to pass on coordinates of survivors and any wreckage, to the first responders.
- The Trinity had a battery issue shortly after takeoff. The system recognized a problem and returned to land without incident. After replacing the battery, no further issues were noted with the system.
- There was an issue with the Sony camera shutter which is utilized by the Yellowscan LiDAR on the X6. The team was able to complete mapping using the Yellowscan LiDAR; however, the camera did not provide the geotagging necessary for development. The team able to perform a work-around in post-production using the location information from the Trinity.
- Operations obscured by mountainous terrain can lead to varied and shifting wind speeds and direction. It did not prevent operations, and the crew was able to adjust the takeoff direction through the Trinity operator software interface. Winds did affect the operation of the small UAS on the first day. The weather station was indicating between 8 and up to

12MPH on the ground but the UAS was indicating as high as 28 mph at 200 ft which limited the operations of the Teledyne (22 mph maximum for position hold). It also impacts battery life as the wind increases the load on the UAS, reducing the total flight time.

- Cooler temperatures early on did cause a slight delay in takeoff on the X6 using a Cube autopilot. There is an optimum temperature that the IMU needs to be at so it will "warm" itself and delay takeoff until the optimum temperature is reached.
- The rugged terrain and lack of roads (essentially a trail) provided a realistic environment for the team to operate out of. The team was required to transfer equipment and personnel into 4-wheel drive vehicles at College Station Ranch before continuing on the trail to the proposed flight operations location (base camp). From there, UAS were used to locate the survivor/wreckage and to guide the "Rescuer." Specific communications (using clock positions or saying left turn, stop, turn, continue forward) were briefed before the rescuer headed out. This points toward specific operational protocols to enhance safety.
- The Matrice EO images were the most effective and would have been very useful during an actual search and rescue. Altitudes remained within Part 107 limitations; however, that did not hinder the ability of the pilot to locate the survivor quickly because of the excellent resolution of the camera and the larger size monitor of the controller.
- There was a question of how well the LiDAR would work for mapping the accident site for post-accident investigation and this was explored. Unfortunately, the LiDAR, in the team's opinion, was not able to provide a high-quality detailed picture of the accident wreckage and would not prove useful for providing high-quality images for post-accident investigation purposes.
- The thermal camera on the Teledyne was very effective and made it much easier to identify a live person (survivor) at an accident site. You can quickly identify potential survivors. This would prove less useful for identifying bodies in a recovery mode after they have cooled to ambient temperatures.

In summary, all of the desired elements were completed. All of the primary and secondary objectives as outlined before the missions were completely met during this Mock Airplane Crash Emergency Response exercise.

Appendix E Contains additional images from the aircraft sensors highlighting their strengths and weaknesses for search and rescue.

6 CONCLUSIONS

The Mock Airplane Crash Emergency Response Test was executed as planned and detailed in the FAA approved Test Plan and Test Cards with UAS flights over the two testing days. The observations and conclusions for this event are presented below. The flights included several mapping flights, free-flight multi-copter with a LiDAR sensor, and multiple small multi-copters to capture images, thermal images, and video.

The 19 different flights covered all the desired muscle movements and system checks. The few lessons learned that impact potential future missions included the following:

- Local flight area obscurations can cause adverse weather conditions and impact flight operations.

- Being able to identify the location of a survivor or even just the wreckage is a necessary tool to assist first responders. There is a need for UAS manufacturers to make it easy for a UAS Pilot to identify the location (latitude and longitude) of the UAS so they can pass the information on to the first responders. In this test, one system would display the UAS location but only when in the map mode, not the camera mode. Another model would give the information, but you had to fly back and download it from the SD card. The one system that could display the "target" location in camera mode was the Matrice which uses a laser range finder.
- Thermal can be more useful than a straight EO camera in particular if there are shadows or cover. Survivors will normally seek cover from the elements (as demonstrated in this test) which will make it more difficult to find them. With thermal, even if just a small portion of their clothed body is exposed, they can display a significant color difference from the surrounding vegetation, dirt, or rocks.
- This scenario had a simulated first responder that the drone was able to guide either by flying over the survivor or using a radio to communicate what direction to walk. If the researchers had simulated a situation where first responders were not readily available or the terrain was such that they could not immediately reach a survivor, the team quickly realized there was no useful way to contact to survivor to relay intentions. Having some type of speaker, possibly dropping a phone or similar communication device, or even having supplemental lighting could assist in this. This is an area worth researching further.
- Cooler temperatures can require longer IMU warmup times delaying takeoff until they are at the required temperature.
- There can be unplanned wind limitations caused by the effects of a crash being located in hilly or mountainous terrain. Funnel effects or turbulence created by winds coming over the top of the hill can affect smaller systems' ability to maintain position or provide a good picture.
- The thermal images on the Teledyne were very effective in being able to see the mock survivor, in particular when looking into the shadow of the hill in the early morning lighting. It was much easier to identify the survivor against the cold ground rocks and to see them despite the vegetation (large Yucca or bushes). Picture quality was adequate to identify the survivor and the large aircraft panels but the zoom wasn't unlimited, so there were specific zoom settings that had to be selected.
- Altitudes varied depending on the payloads. The UAS doing visual search was one hundred to approximately two hundred feet AGL. The Trinity was flown at three hundred and eighty-three feet AGL for mapping and the X6 with LiDAR was flown at two hundred and sixty-two feet AGL.
- The DJI Matrice had the best zoom and picture quality. The Skydio 2 was not quite as detailed a picture as the Matrice however it was more than adequate for the purpose of identifying and assisting in mapping the wreckage site.
- The DJI Matrice has superior zoom and would also take a stand-off picture as well as a close-up when the photo trigger was pressed. This was useful in determining where the object was that you were zooming in on.
- The LiDAR and Multispec cameras were not useful for post-accident investigation or in determining if the crash site was cleared of all debris. It was unable to sufficiently paint

the crash objects well enough to differentiate them from the rocks, boulders, or plants. An increased scale of objects may deliver more visible results, but will still lose fidelity on smaller items.

As noted in the test plans, there were a number of primary and secondary objectives for these flights. In summary, these objectives and the assessment of these are provided below. Many of these are similar to the assessments from the previous tests.

Mock Airplane Crash Emergency Response test objectives assessment:

1. Assess the usability, benefits, and drawbacks of UAS and sensors for a specific disaster, recovery, and response operation.
    a. This was adequately provided for the Mock Airplane Crash Emergency Response by using the Skydios, the Teledyne, and the Matrice 30 multi-copters.
    b. The Matrice provided excellent EO pictures and good zoom capability.
    c. The Teledyne with its thermal camera was able to quickly identify heat signatures which is very useful when trying to find survivors.
    d. The EO maps generated by the Skydio and the DJI Matrice only took approximately 20 minutes to generate on-site and could provide good detail for first responders and post-accident investigation.
    e. The multi-rotors required a very small launch location footprint to operate, easily transported via ground vehicle to the accident site.
2. Utilize visual and thermal sensors to identify the crash location.
    a. The multi-rotor aircraft used for this function performed extremely well providing quality visuals during flight and providing the incident commander with actionable real time information. It also made it much easier to find the survivor by either providing voice commands as to what direction to go or, literally hovering in the vicinity of the survivor, allowing the first responder to locate them.
    b. Matrice
        i. The Matrices' optical camera provided the best overviews for looking at locations on demand. There may be additional resources that could be used, but this aircraft and sensors fulfilled this requirement well.
        ii. The Matrice had a higher quality camera that gave the Matrice a standoff capability which could be useful in high wind conditions near obstacles.
    c. Skydio
        i. The Skydios' optical camera proved to be a very flexible tool to look at the crash site. This aircraft and sensors fulfilled this requirement well, though the camera was not of as high a quality as the Matrice.
        ii. Flying time was not quite as long as for the Matrice. Winds were in the 20 mph range while flying at the 100 to 200 ft AGL altitude which was a factor.
    d. Teledyne
        i. The Teledyne's electro-optical camera had limited zoom and poor quality utilizing a digital zoom.
        ii. The thermal camera was able to identify the crash location via the heat source of the hazard and the survivor and a reduced ability to see other crash parts.

    e. Real time visuals as backup could be viewed through all of the search and identify aircraft controllers.
3. Utilize visual and thermal sensors to identify and locate survivors and hazards.
    a. Matrice
        i. The picture quality of the Matrice EO camera was unmatched in this test providing the clearest picture through all zoom levels.
        ii. This clear picture did allow the pilot to identify the hazard quickly but relied on the pilot to spot the hazard while scanning the area.
    b. Skydio
        i. The Skydio was the only aircraft that required multiple flights to locate the survivor.
        ii. The pilot of the Skydio was unable to locate the hazard and warn the first responder in their search before the responder approached the crash site.
    c. Teledyne
        i. The thermal camera is the Teledyne's greatest asset allowing the pilot to pick out the survivor and hazard easily against the rugged terrain.
        ii. The ability to switch back to the EO camera allowed the pilot to identify the heat source and report this to the first responder.
4. Utilize sensor and imaging systems to map the area before it is disturbed beyond what is required for first response efforts.
    a. The Skydio and the Matrice were able to quickly map the areas and provide detailed maps of the wreckage area which could be processed on-site within twenty minutes.
    b. Several detailed EO and thermal, images were generated before and after the Mock Airplane Crash.
5. Utilize sensor and imaging systems to map the area after for post-remediation assessment.
    a. LiDAR and Multispec cameras did not provide the detail necessary to determine if smaller items were collected from an accident site. Larger items such as a wing or fuselage could potentially be seen; however, those are easily identified by someone on the ground and would not be helpful in a cleanup operation.
    b. The EO camera images from the Trinity were most effective for identifying the Mock Crash parts.
6. Provide guidance and lessons learned from flight operations.
    a. Detailed lessons learned were collected each of the two days throughout this mission. The general lists are presented above. Some of these items are purely specific to the team's flight operations while some are much broader and have import to the program products.

Mock Airplane Crash Emergency Response Test secondary test objectives assessment:

1. Assess the data products and quality/resolution of the produced composite images.
    a. Figure 19 gives an example of the Skydio camera (left image) with 1.67 cm/pix and the Matrice 30 (right image) with a 1.16 cm/pix resolution with a scale of 37.4 cm.
    b. EO and Thermal cameras can provide instant viewing for the UAS pilot who can relay that information to first responders to assist in locating a crash site and possible survivors or hazards. The Skydio X2E had an EO camera with a color still resolution of 4056 x 3040 (12MP). The Skydio 2 had 4056 x 3040 (12MP) and the

Matrice 30 had 48MP 1/2" CMOS. The Teledyne had an EO with 16MP standard and the Thermal Camera resolution was 640 x 512 radiometric.

c. LiDAR and Multispec products take considerable time to process and must be done off-site. Ultimately, they did not provide the detail necessary to identify small parts or debris from an airplane or helicopter crash.

d. Overflights with fixed wing aircraft for mapping were flown higher than normal due to the crash site being located at the base of a two-hundred-foot hill. This reduced the detail of the mapping pictures for LiDAR and Multispec. A tradeoff can be performed before flight to assess product quality/resolution, flight altitude, flight time, and post-processing time.

e. As previously noted, altitudes for flight operations can be driven by system and regulatory limitations, performance/operations (optimum altitudes for payload/mapping to be effective), and safe standoff distances and viewing angles for the event (better cameras allowed a longer standoff from obstacles such as hills/mountains).

2. Determine the proper coordination procedures needed at the local, state, and/or federal levels.
   a. It is vital for first responders and UAS operators the work and train together before conducting real search and rescue. The use of common language via radio when directing personnel to the site is also vitally important to save time and provide a safer environment for the first responders.
   b. Regular training with first responders will provide the UAS pilot with the necessary experience to fully utilize the capabilities of their UAS. This requires coordination with potential users to develop those procedures and have familiarity with the system's capabilities.

6.1 Future Work

This Mock Airplane Crash Emergency Response test concludes the specific work for this effort and therefore is not directly tied into any future work. It is worth noting some related potential future work. These UAS were able to provide a two-dimensional visual and mapping but can also provide a standoff three-dimensional picture that is very useful in conducting post-accident investigations. They also provide excellent situational awareness when being able to assist rescue personnel in locating potential survivors. This was very evident when the rescuer was within 30 feet of the mock survivor, and they still were unable to see them.

Potential follow-up activities could include the development of operational protocols for altitudes, standoff distances, etc. to ensure safe operations and to provide the best viewing angle to identify people or objects (post-accident investigation) on the ground. A tradeoff can be performed to assess product quality/resolution, flight altitude, flight time, and post-processing time and provide the UAS operator or site lead a table or plots that present these trades for decision purposes. Adjusted flight altitudes may be beyond Part 107 limits. Definition, development, and testing of onboard systems for UAS temperature and wind speeds and direction may provide UAS health status to improve operational safety. Winds, in particular in an area with hills/mountainous terrain, can be a significant limiting factor on smaller UAS operability. Another area that should be pursued is the addition of some type of communication capability with a potential survivor. This would require the development of some type of added equipment to the UAS such as a speaker or the ability to release a radio or cell phone.

Finally, a potential follow-up activity could be the development of a set of desired mapping protocols or criteria that would support the accident investigators or post-cleanup crews. It is clear that areas can be effectively mapped pre and post-events, but what quality and resolution are actually needed to support their functions for both rescue operations and accident investigation/post-clean up needs to be further tested.

Appendix A: A62 Test Plan – NMSU Mock Airplane Crash Emergency Response Test

(See attached document)

Appendix B: A62 Test Cards – NMSU Mock Airplane Crash Emergency Response Test

(See attached document)

Appendix C: A62 Mock Airplane Crash Emergency Response Test Site Survey

(See attached document)

Appendix D: A62 Mock Airplane Crash Emergency Response Test Flight Log and Weather Data

Test #	Loc	Flt Objective	UAV/Sensor	External Pilot	Internal Pilot	Launch Area VO	Alt (Ft)	Launch	Land	Duration
1. Skydio X2	CR	ID Crash Site	Skydio X2 (4K60P HDR Camera)	J. Angel		J. Fisher	150	08:39	08:57	0:18:00
1. Skydio X2	CR	ID Crash Site	Skydio X2 (4K60P HDR Camera)	J. Angel		J. Fisher	150	08:59	09:08	0:09:00
2. DJI M30	CR	ID Survivors	DJI M30	J. Millette		K. Common	150	09:12	09:28	0:16:00
2. DJI M30	CR	Pre-Mapping	DJI M30	J. Millette		K. Common	150	09:35	09:42	0:07:00
4. Skydio 2	CR	Pre-Mapping	Skydio 2	J. Fisher		J. Angel	150	10:06	10:12	0:06:00
2. DJI M30	CR	Pre-Mapping	DJI M30	J. Millette		J. Fisher	150	10:31	10:38	0:07:00
3. Teledyne SIRAS	CR	ID Survivors	Teledyne SIRAS (EO/IO)	K. Common		B. Gardner	200	08:41	08:44	0:03:00
3. Teledyne SIRAS	CR	ID Survivors	Teledyne SIRAS (EO/IO)	K. Common		B. Gardner	200	08:51	09:04	0:13:00
8. NMSU X6 with LiDAR	CR	Post-Mapping	X6 (LiDAR - Yellowscan)	J. Fisher	J. Millette	K. Common	260	09:43	09:51	0:08:00
7. Mapping UAS (Sony RX1-II)	CR	Post-Mapping	Trinity Pro (EO)	J. Angel	AJ. Parra	K. Common	300	10:05	10:13	0:08:00
8. NMSU X6 with LiDAR	CR	Post-Mapping	X6 (LiDAR - Yellowscan)	J. Fisher	J. Millette	B. Gardner	260	10:33	10:41	0:08:00
5. LiDAR Mapping UAS (Qube240)	CR	Post-Mapping	Trinity Pro (LiDAR)	J. Angel	AJ. Parra	J. Ponce de Leon	260	10:47	10:55	0:08:00
6. Mapping UAS (Altum-PT Multi-Spec)	CR	Post-Mapping	Trinity Pro (Multi)	J. Angel	AJ. Parra	J. Ponce de Leon	260	11:15	11:23	0:08:00
8. NMSU X6 with LiDAR	CR	Post-Mapping	X6 (LiDAR - Yellowscan)	J. Millette	J. Fisher	R. Saenz	260	11:42	11:50	0:08:00
8. NMSU X6 with LiDAR	CR	Post-Mapping	X6 (LiDAR - Yellowscan)	J. Millette	J. Fisher	R. Saenz	260	12:26	12:34	0:08:00
6. Mapping UAS (Altum-PT Multi-Spec)	CR	Post-Mapping	Trinity Pro (Multi)	J. Angel	AJ. Parra	K. Common	260	12:44	12:53	0:09:00
5. LiDAR Mapping UAS (Qube240)	CR	Post-Mapping	Trinity Pro (LiDAR)	J. Angel	AJ. Parra	K. Common	260	01:07	01:15	0:08:00
7. Mapping UAS (Sony RX1-II)	CR	Post-Mapping	Trinity Pro (EO)	K. Common	AJ. Parra	K. Common	300	01:29	01:36	0:07:00

Table 2. Mock Crash Flight Log.

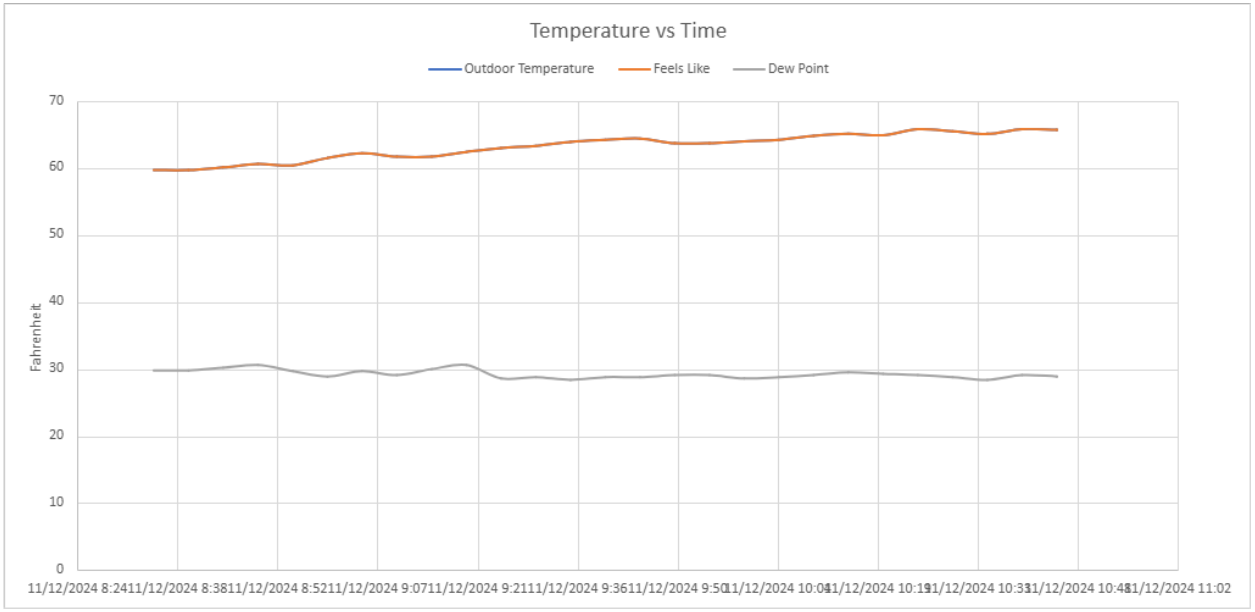

Figure 35. Temperature November 12, 2024.

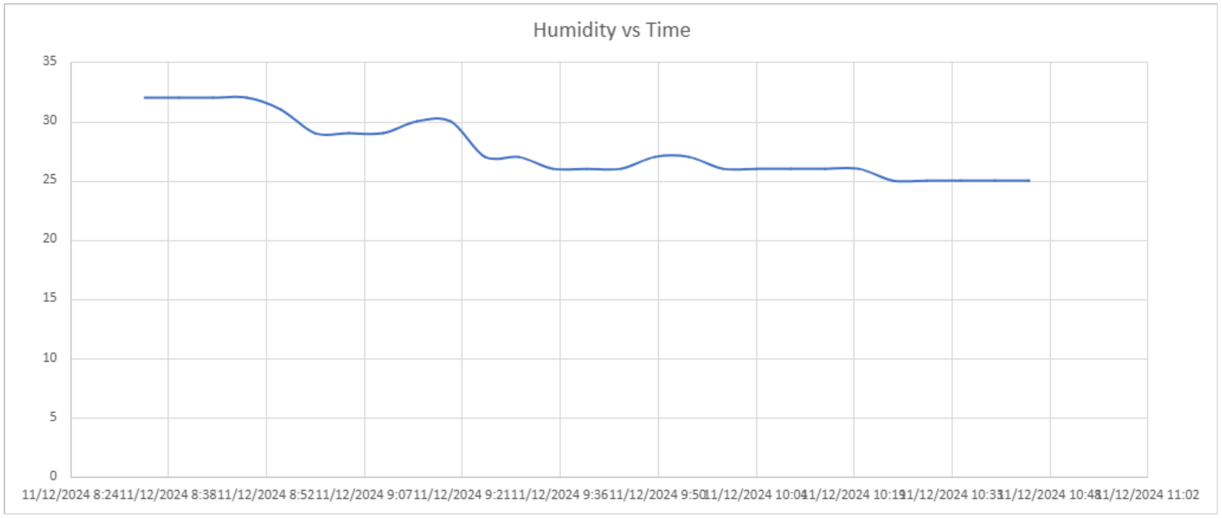

Figure 36. Humidity November 12, 2024.

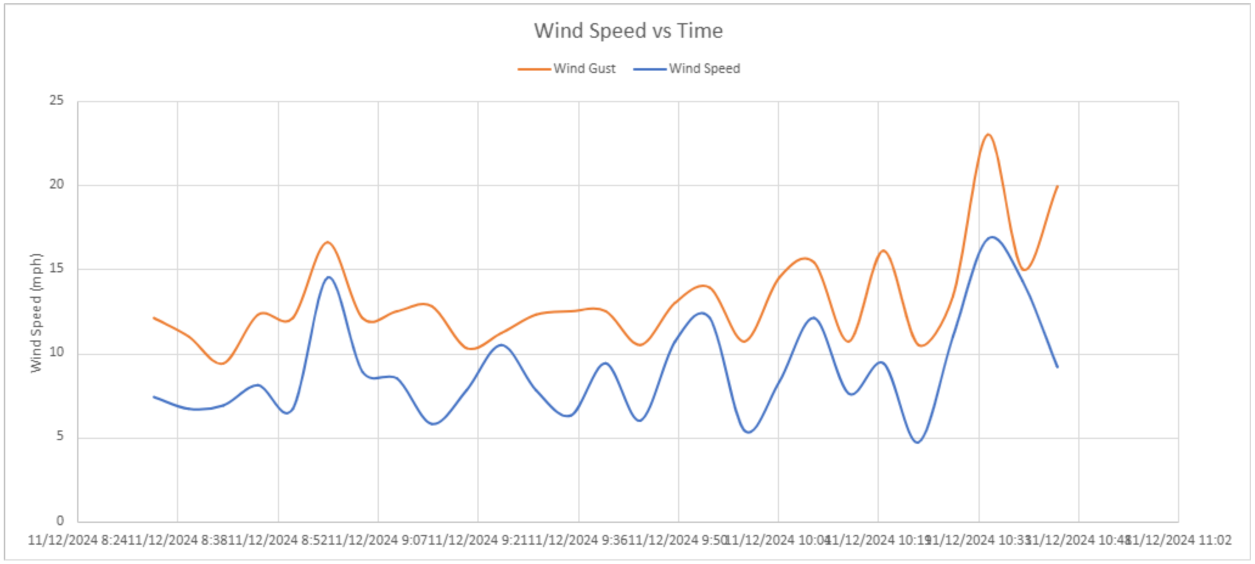

Figure 37. Wind Speed November 12, 2024.

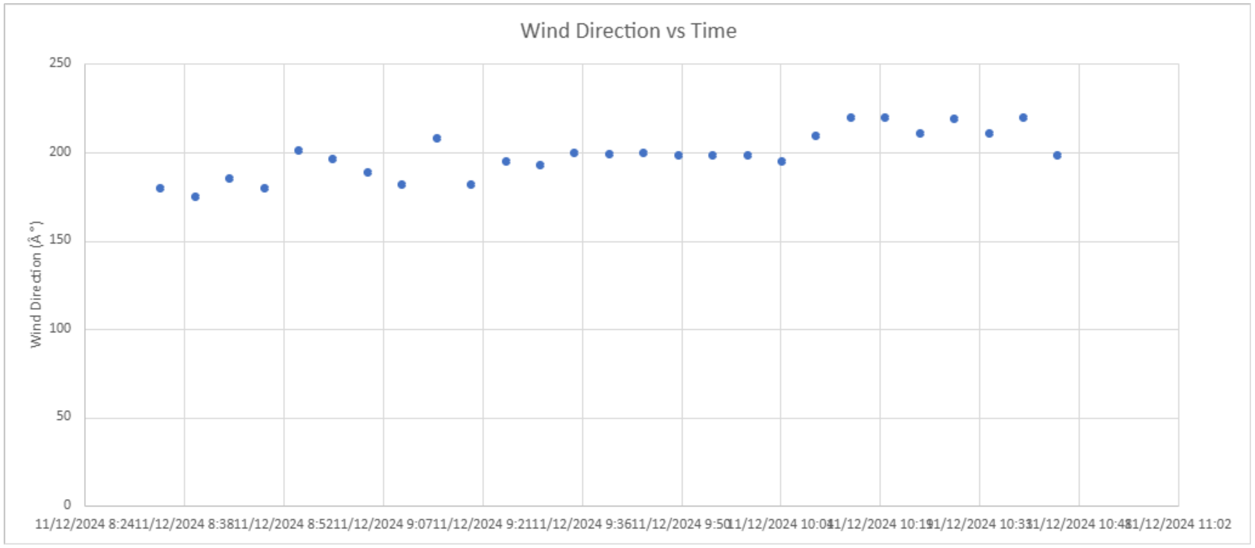

Figure 38. Wind Direction November 12, 2024.

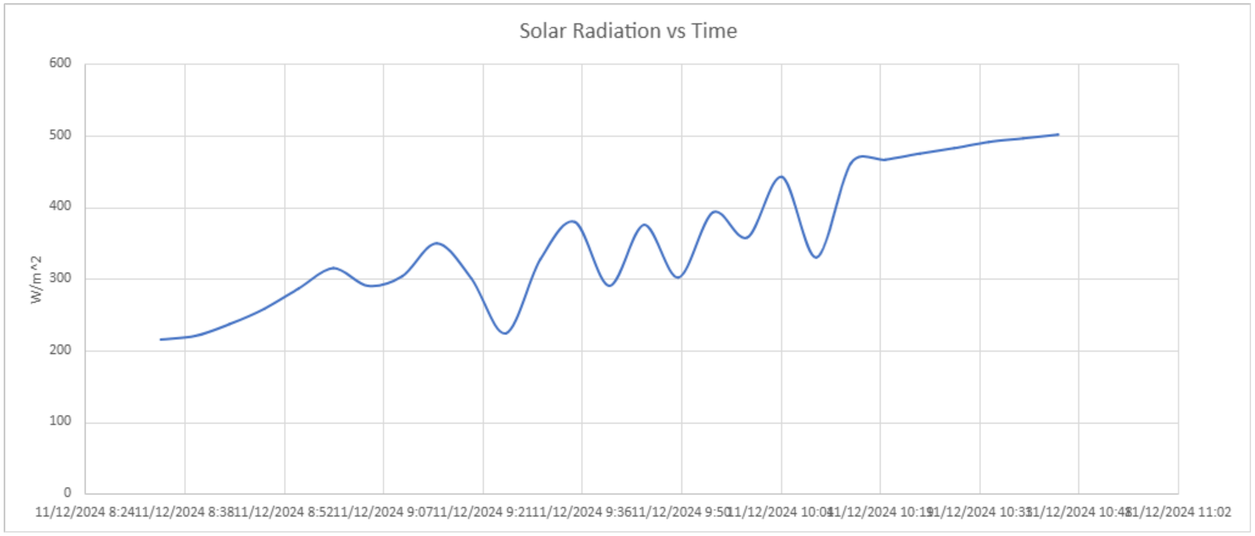

Figure 39. Solar Radiation November 12, 2024.

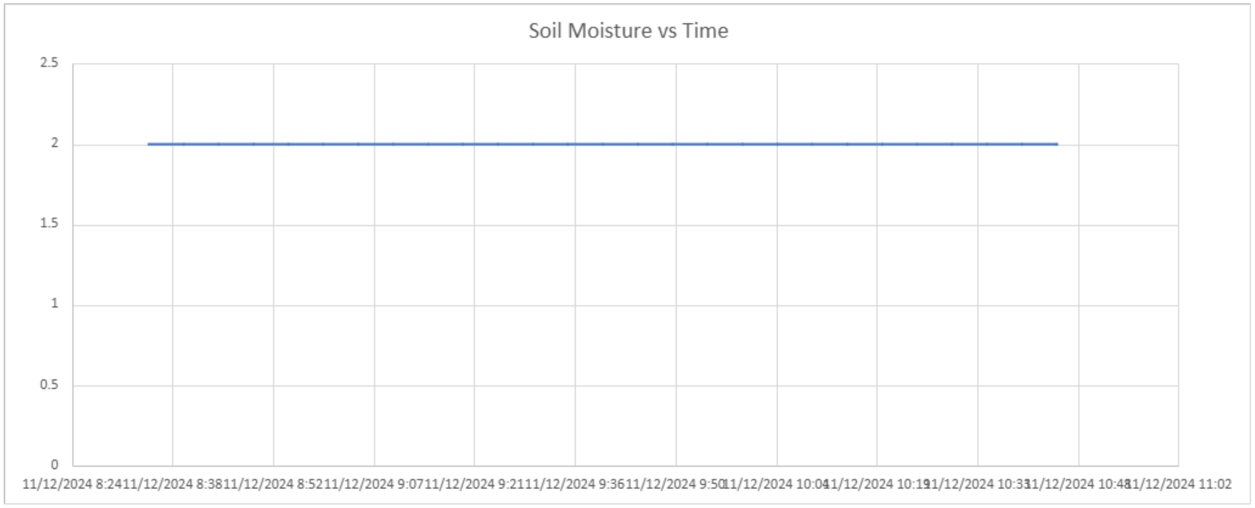

Figure 40. Soil Moisture November 12, 2024.

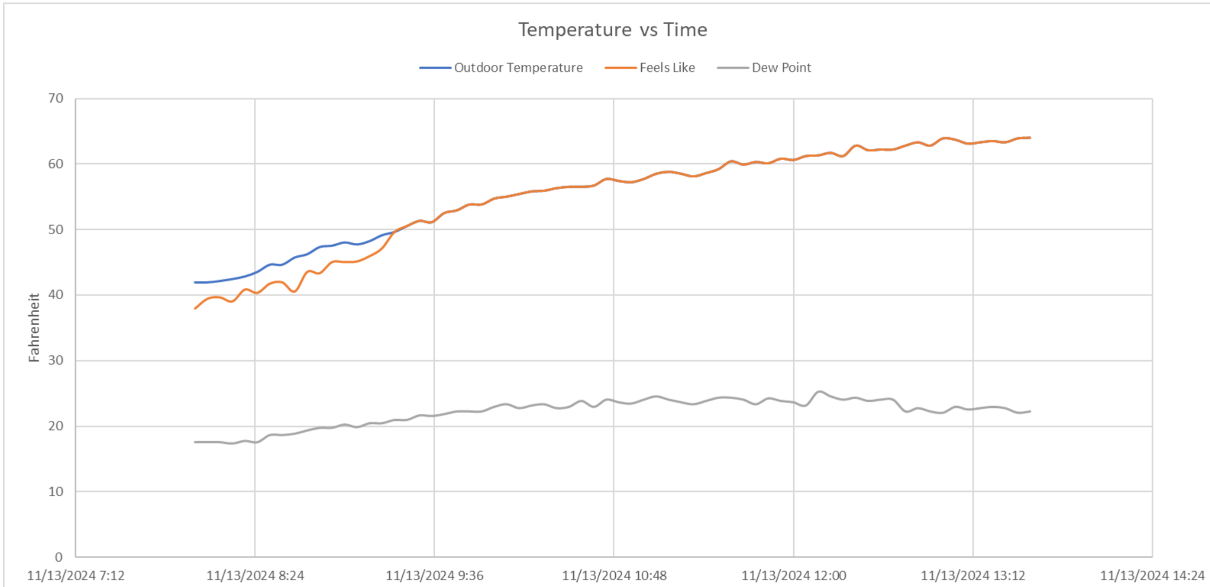

Figure 41. Temperature November 13, 2024.

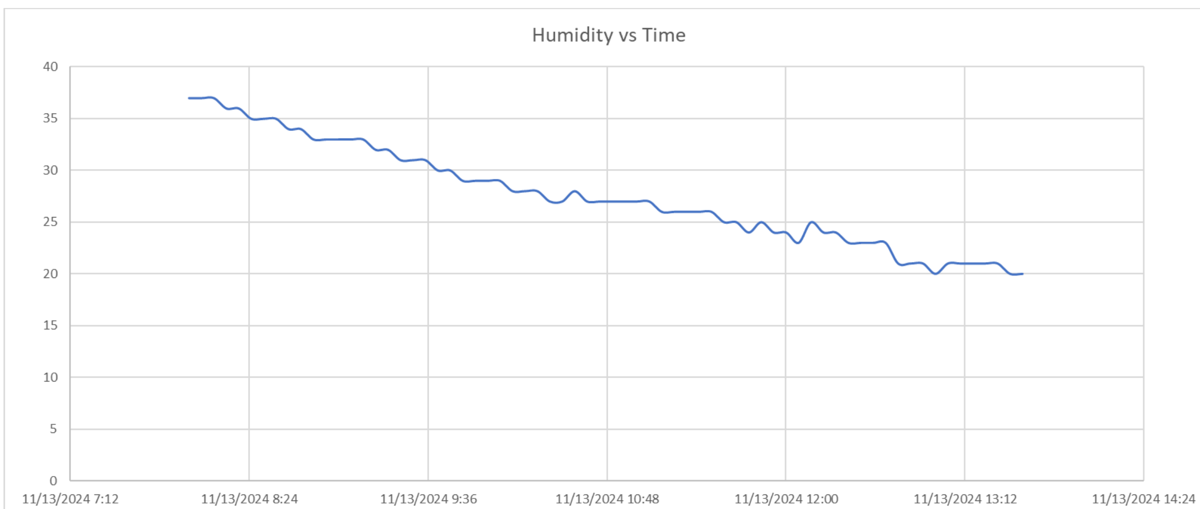

Figure 42. Humidity November 13, 2024.

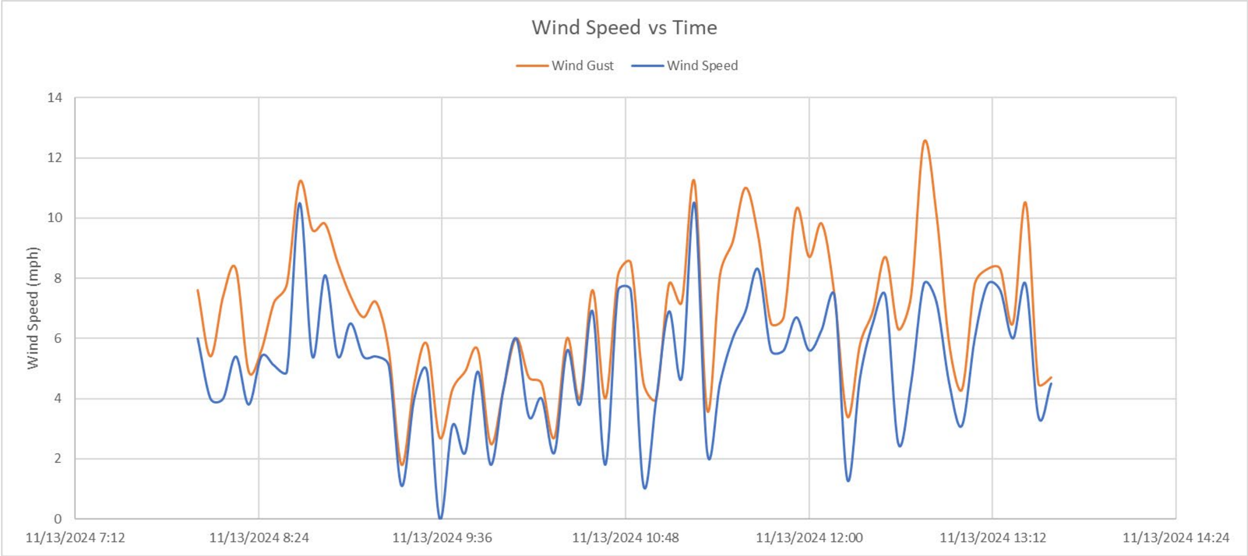

Figure 43. Wind Speed November 13, 2024.

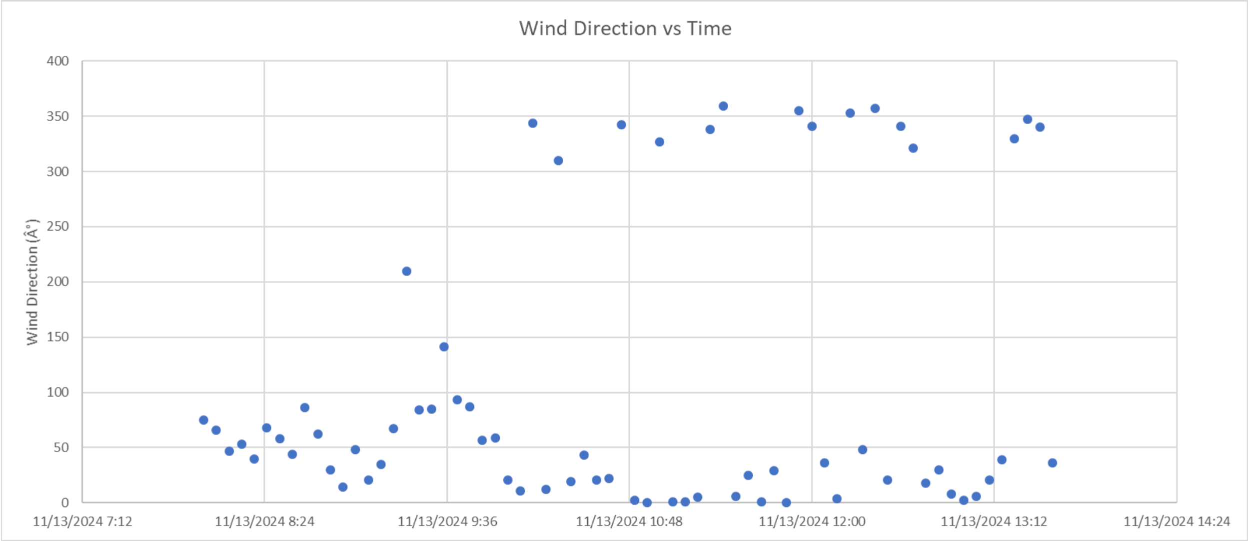

Figure 44. Wind Direction November 13, 2024.

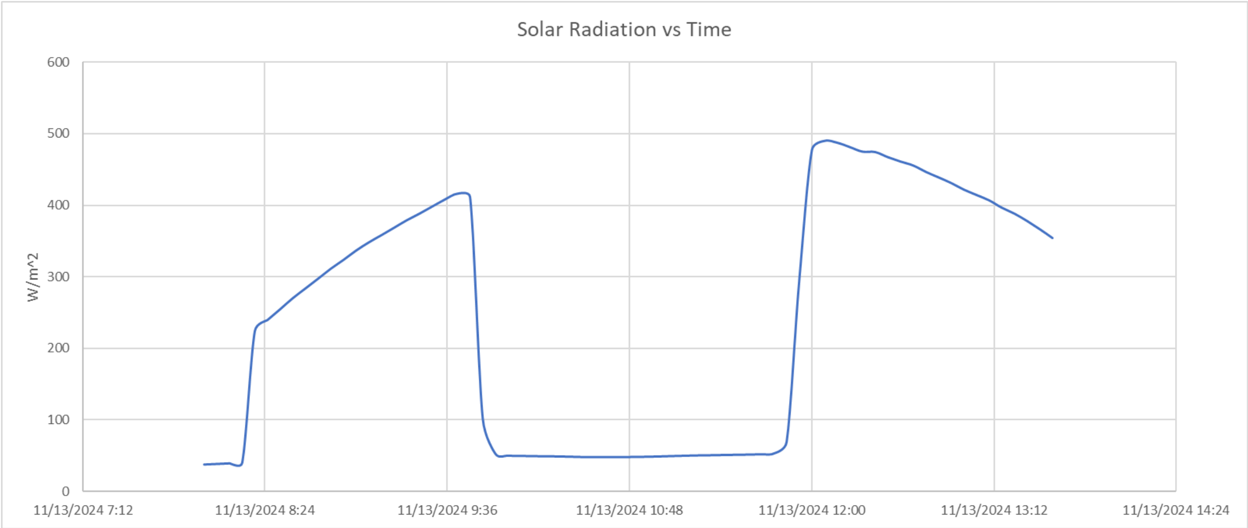

Figure 45. Solar Radiation November 13, 2024.

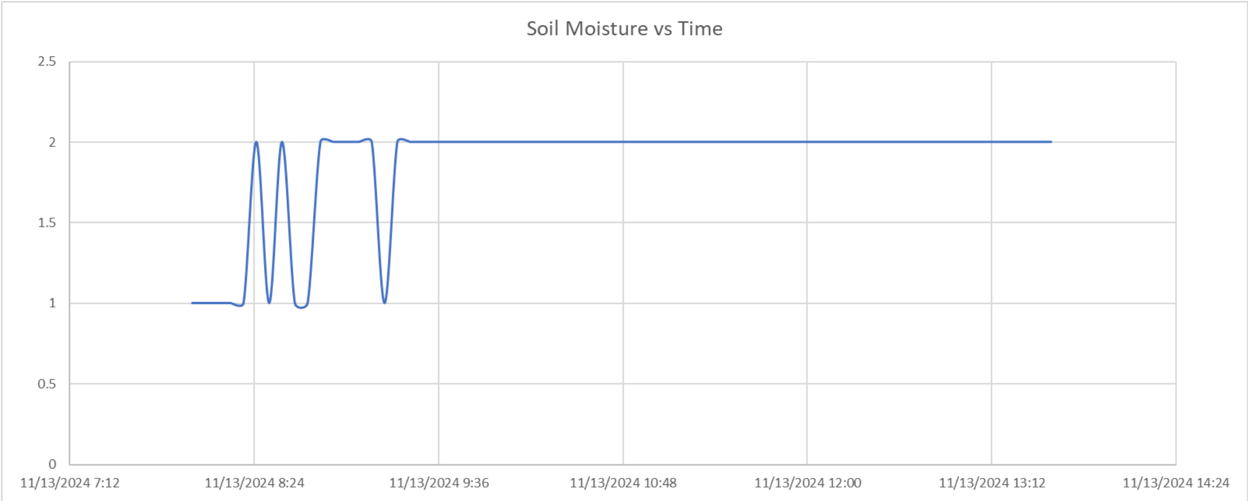

Figure 46. Soil Moisture November 13, 2024.

Appendix E: A62 Mock Airplane Crash Emergency Response Test Images


Figure 47. Mock Crash Site Looking West.


Figure 48. Mock Crash Items #21 (metal plate) and 17 (threaded metal pipe).

Figure 49. Mock Crash Item #3 (fuselage w/o canopy) and #4 (fuselage canopy).

Figure 50. Mock Crash Item #6 (right wing).

Figure 51. Mock Crash Item #17 (threaded metal pipe) and #21 (metal plate #1).

Figure 52. Mock Crash Item #1 (left wing missing flap).

Figure 53. Mock Crash Item #16 (large metal pipe).

Figure 54. Mock Crash Item #8 (engine cowling top).

Figure 55. Mock Crash Item #20 (metal frame).

Figure 56. Mock Crash Item #14 (small metal pipe).

Figure 57. Mock Crash Item #19 (air hose) and #18 (shielded cable).

Figure 58. Mock Crash Item #9 (engine cowling bottom).

Figure 59. Mock Crash Item #22 (metal plate #2).

Figure 60. Mock Crash Item #7 (horizontal stabilizer) and #13 (90 deg metal).

Figure 61. Mock Crash Item #2 (left flap).

Figure 62. Mock Crash Item #15 (medium metal pipe).

Figure 63. Mock Crash Item #25 (junction box).

Figure 64. Mock Crash Item #10 (right boom/vertical stabilizer).

Figure 65. Mock Crash Item #5 (center wing).

Figure 66. Mock Crash Item #11 (left boom/vertical stabilizer).

Figure 67. Mock Crash Item #23 (propane heater) and #24 (propane tank).

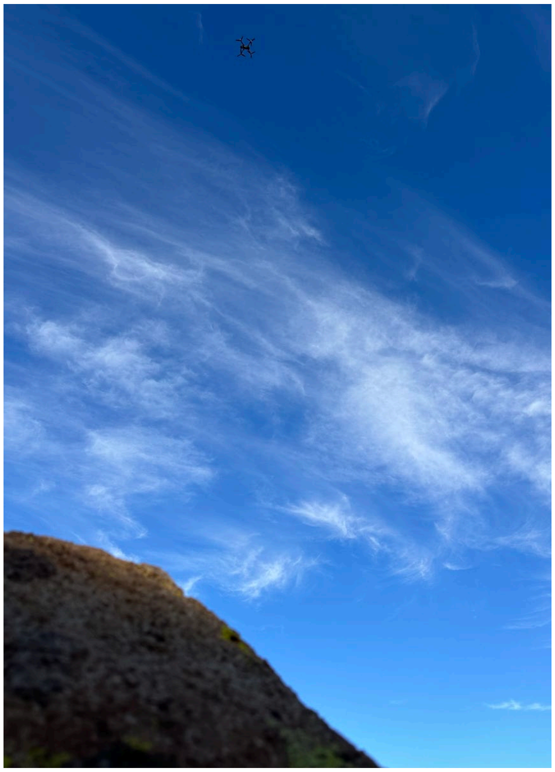

Figure 68. Survivor view of Matrice.

Figure 69. Close image of Crash Site and Hazard from Matrice.

Figure 70. Close view of hazard (red heater in center of frame) from Matrice.

Figure 71. Survivor (right) and First Responder (left) from above by Matrice.

Figure 72. Thermal zoom view of hazard displaying pixelization with digital zoom from Teledyne.

Figure 73. Thermal view of First Responder driving down road to crash site from Teledyne.

Figure 74. Thermal view first responder and hazard from Teledyne.

Figure 75. Wide view of operational area, mock crash site on right edge of photo.

Figure 76. Pilot Albert Parra running the Trinity Checklist.

Figure 77. Weather station display available to pilots during operation.

Figure 78. Team nearing completion of flight operations on second day.