A11L.UAS.68 – A84 Disaster Preparedness and Emergency Response Phase IV: Task 1 Review of Previous Phases

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16. Abstract
This report reflects the findings from a comprehensive review of previous phases (Phases A28, 52, and A62) involving Uncrewed Aircraft Systems (UAS) in disaster preparedness and response. Key findings highlight the need for standardized regulations, real-world deployment, technological advancement, and ethical considerations. Task 1 recommends that A84 focus on formalizing drone use protocols, enhancing technology and data systems, and evaluating long-term community impacts. This work underscores UAS as a vital tool for safer, more efficient disaster response and recovery.

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3D	Three-dimensional
ADS-B	Automatic Dependent Surveillance–Broadcast
AGL	Above Ground Level
AI	Artificial Intelligence
AOA	Airport Operations Area
AOBD	Air Operations Branch Director
ASSURE	Alliance for System Safety of UAS through Research Excellence
ASTM	American Society for Testing and Materials
ATC	Air Traffic Control
BVLOS	Beyond Visual Line of Sight
CDC	Center for Disease Control and Prevention
CFR	Code of Federal Regulations
CISA	Cybersecurity and Infrastructure Security Agency
COA	Certificate of Authorization or Waiver
CONOPS	Concept of Operations
COP	Common Operating Picture
CORS	Continuously Operating Reference Stations
C-UAS	Counter UAS
CURSE	Catastrophic UAS Remote Sensing Exercise
DAA	Detect and Avoid
DAART	Domestic Operations Awareness and Assessment Response Tool
DHS	Department of Homeland Security
DII	Demographically Identifiable Information
DIU	Defense Innovation Unit
DLI	Divert and Land Immediately
EMS	Emergency Medical Service
EO	Electro-Optical
EOC	Emergency Operations Center
EVLOS	Extended Visual Line of Sight
EXIF	Exchangeable Image File Format
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Agency
FIMS	Flight Information Management System
FLIR	Forward-Looking Infrared

FPV	First Person View
GCS	Ground Control Station
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HAZMAT	Hazardous Materials
HSV	Huntsville International Airport
ICS	Incident Command System
IFR	Instrument Flight Rules
IMT	Incident Management Team
IoT	Internet of Things
IR	Thermal Infrared
iUAS	Intermediate UAS
JPEG	Joint Photographic Experts Group
KSU	Kansas State University
LAANC	Low Altitude Approval and Notification Capability
LiDAR	Light Detection and Ranging
lUAS	Large UAS
MBSE	Model-Based Systems Engineering
ML	Machine Learning
MOPS	Minimum Operational Proficiency Standards
MSU	Mississippi State University
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NCSU	North Caroline State University
NDAA	National Defense Authorization Act
NFPA	National Fire Protection Association
NIST	National Institute of Standards and Technology
NMSU	New Mexico State University
NOAA	National Oceanic and Atmospheric Administration
NOTAM	Notice to Airmen
NWCG	National Wildfire Coordinating Group
OOP	Operations Over People
ORA	Operational Risk Assessment
PIC	Pilot In Command
PII	Personally Identifiable Information

PPK	Post-Processed Kinematic
RID	Remote Identification
RTB	Return to Base
RTK	Real-Time Kinematic
SAR	Search and Rescue
SARCOP	Search & Rescue Common Operating Platform
SEOC	State Emergency Operations Center
SGI	Special Governmental Interest
SOP	Standard Operating Procedures
SOSC	System Operations Support Center
sUAS	Small UAS
TAK	Team Awareness Kit
TER	Terminate Flight
TFR	Temporary Flight Restriction
UAF	University of Alaska Fairbanks
UAH	University of Alabama Huntsville
UAS	Uncrewed Aircraft Systems
UAV	Unmanned Aerial Vehicle
US	United States
UTM	UAS Traffic Management
UVM	University of Vermont
VCGI	Vermont Center for Geographic Information
VFR	Visual Flight Rules
VIP	Very Important Person
VLOS	Visual Line of Sight
VO	Visual Observer
VPN	Virtual Private Network
VTOL	Vertical Take-Off and Landing
VTrans	Vermont Agency of Transportation

EXECUTIVE SUMMARY

The A84 ASSURE project initiated by the Federal Aviation Administration (FAA), known as Disaster Preparedness and Response Phase IV and commonly referred to as "Disaster Prep", is the fourth phase of a series of efforts to understand the use of Uncrewed Aircraft Systems (UAS) for disaster scenarios. The A84 project is comprised of five tasks. The objective of Task 1 for A84, was to complete a comprehensive deep dive into the previous three phases of Disaster Prep, analyzing the utilization of UAS during natural and man-made disasters, primarily in preparedness and response efforts. After a complete review of previous reports, the Task 1 effort found that there are overarching themes to the lessons learned, gaps, and recommendations that will inform the objectives of A84. In summary, the first phase of Disaster Prep, A28, focused on past disasters to understand how drones were used and what worked well. The team interviewed emergency responders and created detailed plans for how drones could be used in different types of emergencies. The second phase of Disaster Prep, A52, tested those plans in real-life practice with events across the country. These included simulations of hurricanes, wildfires, and medical deliveries. The A52 team learned that drones could help reduce response times, improve teamwork between agencies, and provide real-time information. They also found that having clear rules, consistent training, and flexible regulations is important for success. In phase three, A62, the focus shifted to new technologies like drone swarms, automated air traffic systems, and better ways to share data between agencies. This phase also looked at how to protect privacy and keep data secure. The team worked closely with communities and emergency agencies to build trust and share best practices.

Based on the findings in this report, it is recommended that A84 focus on creating and testing standard rules for drone use in disasters, using drones in real emergencies, improving drone technology and data systems, studying the long-term impact of drones on communities, and making sure drone use is ethical, legal, and respects privacy. UAS have the ability to reach dangerous or hard-to-access areas, collect valuable data, and help emergency teams make better decisions. UAS enable faster, safer, and more effective disaster response efforts. The work conducted in the fourth phase of Disaster Prep lays the foundation for using UAS as a powerful tool in emergency response, helping communities stay safer and recover faster when disaster strikes. Continuation of this research is imperative as previous phases have shown the utility of UAS during emergency situations.

1 INTRODUCTION & BACKGROUND

The FAA's Center for Excellence for UAS Research, Alliance for System Safety of UAS through Research Excellence (ASSURE) disaster response research projects aim to enhance the effectiveness and efficiency of disaster preparedness and response through the integration of UAS. This report analyzes the three completed phases of the project (A28, A52, and A62) to inform the objectives and research priorities for Phase IV (A84). Each phase contributed unique insights and addressed specific challenges related to UAS integration in disaster scenarios.

- **Phase I (A28)** focused on developing Concepts of Operations (CONOPs) by analyzing historical disaster events and identifying how UAS had been or could be effectively deployed. The phase included stakeholder interviews, use case modeling, and risk assessments to inform future operational planning and regulatory development.
- **Phase II (A52)** built upon A28 by conducting real-world demonstrations, workshops, and functional exercises across the United States (US) to evaluate UAS performance in disaster scenarios such as hurricanes, oil spills, and medical deliveries. This phase emphasized interagency coordination, operational proficiency, and the development of the "Beyond Part 107" guidance document to support public safety UAS operations within the National Airspace System (NAS).
- **Phase III (A62)** expanded the research to include emerging technologies (e.g., UAS swarms, automation, Remote Identification (RID)), data sharing frameworks, and policy analysis. It focused on refining regulatory structures, identifying new use cases, and addressing cybersecurity, command and control, and multi-UAS coordination. A62 also examined the impacts of legislation like the National Defense Authorization Act (NDAA) and explored the feasibility of public safety pilot ratings and standardized disaster response protocols.

This analysis will serve as a foundation for developing a comprehensive research plan for A84, ensuring the project's continued progress toward its goal of establishing a national framework for UAS disaster response.

2 OUTCOMES OF PHASE I (A28)

2.1 Overview of Research Phase

This project entitled "A28_A11L.UAS.68: Disaster Preparedness and Emergency Response" was oriented toward the development of CONOPs likely to be encountered and appropriate to various kinds of natural and man-made disasters.

The A28 team evaluated dozens of historical disasters – hurricanes, tornadoes, floods, wind events, volcanoes, seismic events, earthquakes, landslides, avalanches, pandemics, oil spills, terrorism, and biohazards – examining each example for ways in which the use of UAS was effective and demonstrated positive value. Each historical event was also examined to determine possible lessons learned that related to drone usage in disaster response situations. Furthermore, surveys and interviews were conducted with personnel at federal, state, and local agencies, academic institutions, and private industry who participate in emergency management and disaster response.

The survey responses provided insight into the current and previous relationships and communications among various agencies engaged in disaster response. The survey also provided current information on the kinds of equipment in use by first responders, how that equipment was being used, what responders' key concerns were, what training they felt they needed, and other insights to aid FAA understanding of the current state of UAS usage in emergency response situations.

Another group within the A28 team examined certain past disasters, focusing on the interorganizational relationships of responders and established communication patterns. The team developed use case diagrams depicting high-level interactions among the entities involved during the disaster. The entities were identified in these diagrams as actors, while the interactions were identified as use cases.

A third group of analysts examined various detailed use cases, again across a wide spectrum of imagined disasters, enumerating the many ways in which various kinds of UAS might be brought into disaster response service. This modeling included the kinds of aircrafts and sensors most appropriate for specific missions, the phase of the disaster within which they would be expected to participate, the hazards associated with their use, the type of flight (Certificate of Waiver or Authorization (COA)/Part 107/Waiver), whether their mission might require Beyond Visual Line of Sight (BVLOS) permissions, the flight details, and the payloads. This group examined the different kinds of data collected and their usefulness. These detailed CONOPs became the "scripts" from which the events conducted under the subsequent A52 effort were derived. Researchers also examined the technological underpinnings that affect and enable the use of UAS in emergency response environments. The study includes a discussion of key challenges associated with these technologies.

2.2 Survey

2.2.1 Overview

The online survey, developed in Qualtrics with input from an expert advisory committee, targeted users and non-users of UAS across six professional sectors. It consisted of 43 questions and two primary branches, directing respondents based on their organization's UAS program status. The survey aimed to gather insights on UAS usage, disaster response, coordination, regulations, barriers, and new technology.

2.2.1.1 Key Findings

- **Participants**: 85 respondents from various sectors, with the largest percentage from the federal government (24%). 38 states were represented.
- **UAS Program**: 15 respondents did not have a UAS program. Most organizations with UAS programs had certified operators, data managers, owned UAS platforms, and had specific policies.
- **Disaster Response**: UAS were commonly used for disaster response, with varied use of occupied aircraft and satellite imagery. Multi-agency exercises involving airspace coordination were frequent in western states.
- **Coordination & Planning**: Coordination was most common among federal, state, and local agencies. Many organizations incorporated UAS into emergency response plans and had dedicated airspace coordinators but reported that funding

was a barrier to participating in future disaster response exercises.

- **Regulations & Safety**: Over half of respondents operated under Part 107 regulations, with approximately a quarter operating under a Part 91 COA, with optimism about RID improving safety. Most had a strong understanding of UAS regulations.
- **Barriers**: Funding was the top internal barrier, followed by leadership buy-in, training, staffing, and data standards. External barriers included federal regulations and restrictions on purchasing equipment based on country of origin.
- **Privacy, Data Sharing, and New Technology**: Sensitive data identified by respondents included faces and license plates. Respondents were generally comfortable with Artificial Intelligence (AI) integration into UAS operations.

2.3 Case Studies

The research team conducted an intense literature survey focusing on a set of known disasters in which UAS played some role between 2006 and 2020. A total of 38 well-documented disasters were reviewed, representing UAS disaster response events in 23 states and one US territory.

2.3.1 Geohazard Case Studies

2.3.1.1 Overview

The case studies highlight various applications of UAS in response to geohazards such as volcanic eruptions, earthquakes, landslides, subsidence, and avalanches across five states and one US territory.

2.3.1.2 Key Findings

UAS were used for real-time monitoring, situational awareness, data collection, and supporting emergency response efforts. Key lessons learned from these case studies include:

- UAS increased safety of emergency responders by providing remote access to actively hazardous areas such as landslides.
- UAS efficiently collected and shared imagery and video that provided rapid and real-time situational awareness of developing events including volcano eruptions, lava flows, landslides, and avalanches.
- Large-scale geohazard disasters required coordination between local, state, and federal agencies involved in the response to allow for safe deployment of UAS resources.
- Imagery and video captured by UAS enabled long-term post-disaster response and recovery efforts. Light Detection and Ranging (LiDAR) and thermal sensors may enhance the applications of UAS data.
- Part 107 waivers provided response with UAS to be conducted more efficiently during response events, particularly a waiver to the altitude limitations of 400 feet above ground level (AGL) in § 107.51 – Operating limitations for Small Unmanned Aircraft.

2.3.2 Weather Event Case Studies

2.3.2.1 Overview

The case studies highlight the use of UAS in 10 states to respond to various weather-related disasters, including hurricanes, tornadoes, microbursts, derechos, and floods.

2.3.2.2 Key Findings

UAS were deployed for Search and Rescue (SAR), situational awareness, damage assessments, and infrastructure evaluations. Key lessons learned from these case studies include:

- Effective UAS responses require coordination between various organizations and agencies. Pre-existing relationships and regular communication enhance the efficiency of operations.
- UAS provide detailed imagery and mapping data that are crucial for damage assessments and situational awareness. Rapid data sharing improves decision-making and forecasting accuracy.
- Common challenges include crowded airspace, loss of cellular networks, and regulatory issues. Addressing these challenges involves coordination with the FAA and other agencies, as well as innovative solutions like providing cellular coverage via UAS.
- UAS operations are often more cost-effective than traditional methods, especially in remote or inaccessible locations. They offer a quicker and safer alternative for SAR and damage assessments.
- The ability of UAS to operate BVLOS, carry flotation devices, and provide live video feeds enhances their utility in responding to the impacts of weather events.

2.3.3 Fire Case Studies

2.3.3.1 Overview

The case studies highlight the use of UAS in six states to respond to wildland and industrial-urban fires.

2.3.3.2 Key Findings

UAS were employed for damage assessments, fire mapping, monitoring, and situational awareness. Key lessons learned include:

- The use of UAS for thermal imaging, three-dimensional (3D) mapping, and remote ignition of fires showcased their advanced capabilities.
- Effective UAS operations required high levels of coordination and communication between various agencies and operators. Challenges included managing airspace, especially with recreational UAS, and ensuring clear communication between crewed aircraft and UAS operators.
- The absence of specific disaster-related regulations and procedures sometimes led to delays and operational difficulties.
- The need to educate recreational UAS operators was identified to prevent interference with emergency operations. Increasing public awareness can help mitigate airspace congestion and enhance overall response efforts.

2.4 Technological/Anthropogenic Case Studies

2.4.1.1 Overview

The case studies highlight the use of UAS in nine states to respond to various technological and anthropogenic disasters, including pandemics, oil spills, terrorism, vehicular accidents, and biohazards.

2.4.1.2 Key Findings

UAS were utilized for medical deliveries, damage assessments following transportation accidents, and situational awareness during biohazards and spills. Key lessons learned from these case studies include:

- UAS imagery and videos were critical for crash scene reconstruction and informed investigations into transportation accidents. UAS allowed for more efficient searching of surrounding terrain for debris and increased the safety of crash investigators.
- Specific UAS sensor packages capable of gas detection can be combined with algorithms to effectively identify leaks of methane and other compounds from infrastructure, including pipelines.
- Delivery of medical supplies and other resources by UAS can enhance the connectivity of rural or isolated communities during an emergency.

2.5 Model-Based Systems Engineering

The Model Based Systems Engineering (MBSE) toolset software was utilized to model three types of diagrams for various disaster scenarios:

- **Block Definition Diagram**: Identified relationships between organizations and responders.
- **Use Case Diagram**: Represented data flow and interfaces between organizations and responders.
- **Activity Diagram**: Showed the control flow of disaster response from the perspective of critical tasks.

A total of six emergencies were modeled, including a hurricane, tornado, flooding, infrastructure collapse, and SAR. For each case, connection information between entities was placed into weighted graphs, which were analyzed using centrality, community detection, and connectivity analyses. These analyses led to managerial recommendations for disaster response agencies.

2.5.1 Key Findings and Recommendations

2.5.1.1 Managerial Insights

As displayed in **Error! Reference source not found.**, the UAS program is the center of disaster information and frequently determines the flow of information during disaster management.

- It is highly recommended to have a specialist dealing with information transport. This specialist should have efficient connections with different disaster management agencies and the ability to deliver timely and accurate information.
- UAS programs belong to the operation and response groups, therefore, it is best to focus on the search and rescue aspects during the disaster rather than social affairs.

- It will be easy for supporting group agencies, such as state departments of transportation, environmental quality, public safety, and the local council of government, to obtain disaster information. Therefore, it is recommended they link with corresponding agencies. For example, the state department of transportation should link directly with the UAS program. There is no need for it to make multiple connections for disaster management.
- For some of the most frequent connections, such as FAA/local Air Traffic Control (ATC), the creation of a hotline for disaster management and coordination is recommended.

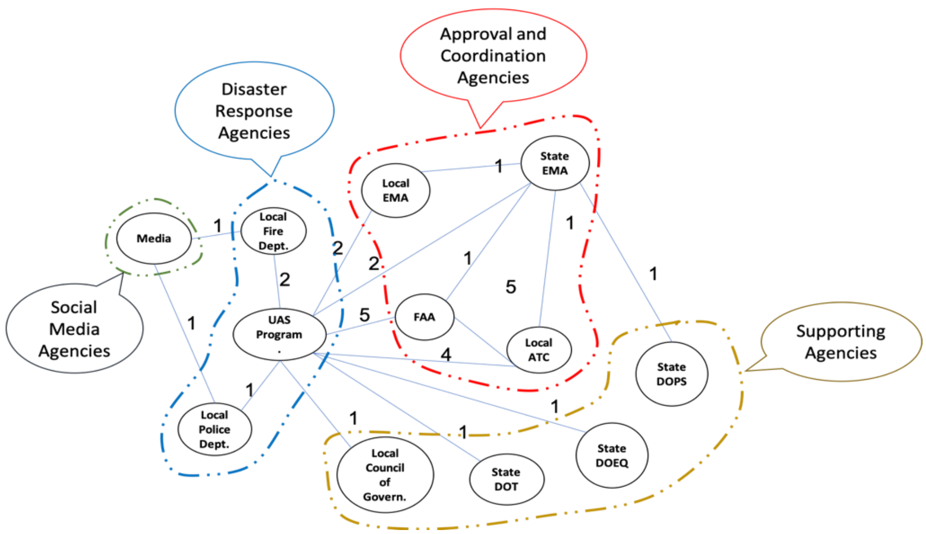

Figure 1. Agency clusters and relationships during emergency response.

2.5.1.2 Operational Insights

The Special Governmental Interest (SGI) process allows for addendums to 14 Code of Federal Regulations (CFR) Part 91 and Part 107 operations for significant and urgent emergency operations or law enforcement activities. This process is managed by the FAA's Air Traffic Management Systems Operations Security (SOSC) in Northern Virginia.

- **Emergency COAs**: Originally established to assist with post-disaster airspace coordination, the SGI process replaced the Emergency COA process near the time of Hurricane Harvey's 2017 landfall. It expanded access to airspace for both public and non-public aircraft operations.
- **Public and Non-Public Operators**: Approximately 60-70% of SGI requests are from public operators, including first responders, law enforcement, and fire response. Non-public operators, such as utility companies, media, and insurance companies, make up the remaining requests.
- **Certification Requirements**: The SGI process requires that the requesting entity has an active COA or CFR Part 107 certification. Having both certifications allows more flexibility in the request process.

- **Request Process**: The SGI addendum process is initiated by submitting the Emergency Operation Request Form. In time-critical situations, verbal SGI addendum authorizations can be issued and followed up by written confirmation.
- **Workload and Efficiency**: The SGI addendum process represents approximately 50% of the SOSC staff workload. The process was considered smooth and efficient, with ongoing efforts to improve collaboration and teamwork between the FAA and disaster response entities.

Temporary Flight Restrictions (TFRs) are a type of Notices to Airmen (NOTAM) issued by the FAA to restrict flight operations within a defined area in U.S. airspace for protection people or property in the air or on the ground. Air traffic managers coordinate TFRs within their jurisdiction, ensuring safe operations for relief aircraft and preventing flight congestion. TFRs are set up for disaster response under 14 CFR Part 91.137, with local ATC facilities acting as primary coordinators. Unique TFRs to UAS disaster response include BVLOS TFRs to extend the visual range of the UAS flight personnel. BVLOS TFRs are granted by the SOSC via SGI addendum requests. Notable recommendations for TFRs include:

- **Proper Setup**: TFRs must be properly set up to ensure safe operations between crewed and uncrewed aircraft.
- **Airspace Management**: Effective management includes block airspace TFRs starting at the surface and extending upward.
- **Size and Scope**: TFRs should be large enough for proper response but small enough to avoid disrupting air traffic.
- **On-Scene Coordination**: Using airborne on-scene coordinators with proper communication equipment is the most effective method of managing a disaster event TFR.
- **FAA Advisory Circular**: The FAA's TFR Advisory Circular (AC No. 91-63D) should be updated to include best practices for coordination between crewed and uncrewed aircraft in disaster response.

2.6 Use Case Development

A series of CONOPS were developed for a unique set of emergency scenarios. Operational Risk Assessments (ORAs) were developed to support the analysis of each CONOPS to ensure UAS missions can be conducted with an acceptable level of risk by identifying and mitigating potential hazards. The ORAs used FAA severity and likelihood decision matrices to assess and adjust risk levels, focusing on adverse operating conditions, external systems, human factors, the UAS itself, and cyber threats.

2.6.1 Airport Terrorism

This CONOPS represents a terrorism event at Huntsville, Alabama International Airport (HSV), including surveillance of ongoing events and disruption and counter measures to the attack.

2.6.1.1 Goals

- Large UAS (lUAS) to provide continuous surveillance and communication.
- Small UAS (sUAS) to respond quickly to specific requests and provide data.
- Tethered UAS to establish fixed surveillance and communication hubs.

- Counter UAS to react to airborne threats and ensure airport safety.

2.6.1.2 Mission Procedures and Approach

- lUAS: Provides real-time data to the Ground Control Station (GCS) and emergency management operations center.
- Tethered sUAS: Positioned at the airport terminal to provide fixed surveillance and communication.
- Mobile sUAS: Flown into the TFR area for low-altitude surveillance and communication.
- Counter UAS: Responds to hostile airborne assets and can deliver supplies to the hazard zone.

2.6.2 Earthquake and Tsunami

This CONOPS prepares a response framework to a large earthquake in South Central Alaska that impacts the Anchorage to the Palmer region; Tsunami warning and then inundation of coastline and impacts Seward; Bridge collapse along highway from Anchorage to Palmer and need to map.

2.6.2.1 Goals

- lUAS: Map the affected region and provide data to the emergency management operations center.
- sUAS:
    - Respond to specific areas like the collapsed bridge and Seward.
    - Support local infrastructure analysis and safety assessment.

2.6.2.2 Mission Procedures and Approach

- lUAS:
    - Conduct high-altitude observations over the disaster area and deliver geospatial locate video feeds.
    - Follow a defined route covering main road networks and communities.
    - Operate BVLOS under Visual Flight Rules (VFR)/Instrument Flight Rules (IFR) conditions
- sUAS #1:
    - Map tsunami impact in Seward using optical video, thermal data, and 3D models.
    - Operate under Part 107 waiver and SGI waiver.
- sUAS #2:
    - Map damage to the bridge between Anchorage and Palmer using optical imagery to create 3D models.
    - Operate under visual line of sight (VLOS) with Part 107 waiver if needed.

2.6.3 Hurricane, Tornado and Flooding

This CONOPS prepares a response framework to a significant hurricane (Category 4) passing onto land near New Orleans with subsequent tornadoes impacting the landscape and communities and then post-event extensive flood waters that continue to impact surrounding communities. A lack of cell-coverage requires airborne communications to support ground teams.

2.6.3.1 Goals

- lUAS: Deliver real-time data to the emergency management operations center for airborne surveillance.
- sUAS:
  - Establish a fixed communications hub for ground operations.
  - Adapt flight patterns based on ground team needs for search and rescue.
  - Provide data on at-risk infrastructure.
  - Map water levels and adapt flight plans based on emergency management needs.

2.6.3.2 Mission Procedures and Approach

- lUAS: Rapid response from HSV, providing high-altitude surveillance and communications over the disaster zone for multiple hours.
- sUAS #1: Tethered to a fixed location within the disaster zone, serving as a communications hub and providing electro-optical (EO) and/or thermal data.
- sUAS #2 & #3: Conduct short, manual flights to support search and rescue operations and assess building safety, providing real-time video feeds to ground teams.
- sUAS #4: Perform long endurance flights to map flooding extent, with predefined routes and adaptable flight plans based on emergency management needs.

2.6.4 Oil Spill

This CONOPS provides a framework for UAS response to an oil spill from the Valdez Terminal onto the surrounding land and into the port of Valdez Harbor in Alaska.

2.6.4.1 Goals

- lUAS: Provide real-time data and possible machine learning from search and rescue data.
- sUAS:
  - Deliver optical video to emergency command center.
  - Capture multispectral images for spill extent analysis.
  - Coordinate multiple sUAS within common airspace over spill.

2.6.4.2 Mission Procedures and Approach

- lUAS:
  - BVLOS operation under VFR/IFR conditions.
  - Stream EO data to operations center; help determine locations for small UAS operations.
  - If available, use Synthetic Aperture Radar data to detect spill on ocean surface.
- sUAS #1:
  - Terminal mapping using EO videos and multispectral images of oil extent on land; orthomosaics and 3D models of terminal damage.
  - Operations under Part 107 and SGI waivers, as needed - VLOS operations if near terminal, BVLOS if flying extended mission across bay.
  - Operates within TFR region and in sync with lUAS operating overhead.

- sUAS #2:
  - Operated from boat in bay under Part 107 regulations (VLOS).
  - Routine or emergency-defined flight pattern to map oil drifting in ocean using EO and/or multispectral sensors.
  - May carry repellent to burn off oil in-situ.

2.6.5 Pandemic – lUAS

This CONOPS provides a framework for the application of lUAS to support a rural community low on critical medical supplies during a pandemic event. The community is isolated with no road access. Crewed systems are unable to fly due to IFR conditions.

2.6.5.1 Goals

- lUAS: Round-trip large UAS operation to supply community with critical cargo. Real-time data of flight route and transfer between flight crews. Mission tracked at both GCS at departure and arrival locations.

2.6.5.2 Mission Procedures and Approach

- lUAS:
  - BVLOS operations with COA or waiver.
  - Transfer of control from flight crew at departure location to flight crew at arrival location mid-flight.
  - Real-time optical data and Detect and Avoid (DAA) tracking from the GCS of both flight crews in parallel.
  - Delivery of critical cargo to rural community and return of lUAS to main hub for future missions.

2.6.6 Pandemic – sUAS

This CONOPS provides a framework for the application of sUAS to support a rural community low on critical medical supplies during a pandemic event. The community is isolated with no road access. Crewed systems are unable to fly due to IFR conditions.

2.6.6.1 Goals

- sUAS: Round-trip sUAS operation to supply community with critical cargo. Real-time data of flight route and transfer between flight crews. Mission tracked at both GCS at departure and arrival locations.

2.6.6.2 Mission Procedures and Approach

- sUAS:
  - VLOS or Extended Visual Line of Sight (EVLOS) operations with Part 107 waiver.
  - Transfer of control from flight crew at departure location to flight crew at arrival location mid-flight.
  - Real-time optical data and tracking from the GCS of both flight crews in parallel.
  - Delivery of critical cargo to rural community and return of sUAS to main hub for future missions.

2.6.7 Train Derailment

This CONOPS provides a framework for the application of sUAS in response to a passenger train derailment that impacts urban infrastructure. Need to perform search and rescue on the derailed carriages and assess safety of the railroad infrastructure.

2.6.7.1 Goals

- lUAS: Provide real-time data to GCS and operations center for airborne surveillance of derailment event.
- sUAS:
  - Capture visible and thermal data to aid ground teams conducting search and rescue. Data is used for virtual reconstruction of crash site to aid investigations.
  - Capture multispectral data around crash site to detect fuel leaks and assist in search and rescue. Data used for virtual reconstruction of crash site to aid investigations.
  - Respond to damaged infrastructure, using EO imagery and video to assess safety and prevent additional disasters.

2.6.7.2 Mission Procedures and Approach

- lUAS:
  - BVLOS operation under VFR/IFR conditions.
  - Stream EO data to operations center; help determine locations for small UAS operations.
- sUAS #1:
  - Conduct short, manual flights to support search and rescue operations and assess building safety, providing real-time video feeds to ground teams and operations center.
  - VLOS operations under Part 107 and SGI waivers.
- sUAS #2:
  - VLOS operations under Part 107 and SGI waivers.
  - Routine or emergency-defined flight pattern to map potential spills of fuel or other hazardous materials with EO and/or multispectral sensors.
- sUAS #3:
  - VLOS operations under Part 107 and SGI waivers, possibility to require EVLOS or BVLOS operations.
  - Real-time EO data feed to operations center of impacted infrastructure.
  - Development of 3D models of infrastructure.

2.6.8 Volcano

This CONOPS provides a framework for the application of sUAS in response to a volcanic eruption with plume and clouds putting population/infrastructure at risk.

2.6.8.1 Goals

- lUAS**:** Conduct high-altitude observations and sample volcanic plumes.
- sUAS:
  - Map the summit and sample the plume.

    - Measure ash and gas concentrations downwind between the volcano and nearby airport.

2.6.8.2 Mission Procedures and Approach

- lUAS:
    - BVLOS operations under VFR/IFR conditions.
    - Operations within and outside of TFR established over summit.
    - Real time EO data feed to operations center and/or volcano observatory.
- sUAS #1:
    - Summit mapping and plume sampling.
    - VLOS operations with Part 107 and SGI waivers.
    - Flown in TFR region, coordinated with lUAS.
    - Real-time electro optical data provided to operations center and/or volcano observatory.
    - Capture mapping data to produce 3D surface model and thermal map of the summit.
- sUAS #2:
    - Vertical profiling of ash and gas concentrations through downwind plume and clouds. Data delivered to volcano observatory in coordination with operations center.
    - Flights timed to match sUAS #1 missions.
    - VLOS operations with Part 107 and SGI waivers.

2.6.9 Wildland Fire – Prescribed Burn

This CONOPS provides a framework for the application of sUAS for a prescribed burn with the ignition of fuels and suppression of the fire.

2.6.9.1 Goals

- sUAS
    - Tethered real-time video feed through duration of event.
    - Mapping data captured pre- and post-burn to assess impacts and effectiveness.
    - Delivery of ignition and retardant materials to initiate and suppress fire.
    - Real-time aerial data provided to operations centers and fire crews.

2.6.9.2 Mission Procedures and Approach

- sUAS #1:
    - Tethered operations. VLOS or EVLOS under VFR conditions.
    - EO and thermal infrared (IR) data provided in real-time and recorded.
    - Remain airborne until operations completed.
- sUAS #2:
    - VLOS operations under Part 107.
    - Provide real-time EO data during capture of imagery and LiDAR data to develop mosaiced mapping imagery and 3D models.
    - Operations prior to and following prescribed burn to assess impact to vegetation and tree canopy.
- sUAS #3:

    - VLOS or EVLOS operation under Part 107 with waivers as needed.
    - Deployment of fire ignition materials to initiate burn.
    - Deployment of fire-retardant materials to suppress burn.
- sUAS #4:
    - VLOS operations under Part 107.
    - EO full motion video in real-time to provide local operations team with assessment of the mission effectiveness.

2.6.10 Wildland Fire

This CONOPS provides a framework for the application of sUAS for a newly reported wildland fire.

2.6.10.1 Goals

- lUAS: Provide real-time data to operations center, fire crews, and in support of sUAS operations.
- sUAS:
    - Map the fire edge using visible and thermal data.
    - Sample the plume and dispersing cloud downwind of the fire.
    - Collect data ahead of the fire spread to support fire weather indices and modeling.
    - Map downwind fire fuels using EO, multispectral, IR, and/or LiDAR data.

2.6.10.2 Mission Procedures and Approach

- lUAS:
    - BVLOS operations under VFR/IFR conditions.
    - Real time EO data feed to operations center and fire crews.
- sUAS #1:
    - Tethered operations. VLOS or EVLOS under VFR conditions.
    - EO and IR data provided in real-time and recorded.
    - Remain airborne until operations are completed.
- sUAS #2:
    - VLOS operations with Part 107 and SGI waivers.
    - Streams EO data to support team to assess fire site.
    - Provides IR data to derive fire intensity and map fire perimeter.
- sUAS #3:
    - EVLOS operations with Part 107 and SGI waivers.
    - Vertical and horizontal profiling of ash and gas concentrations through downwind plume and clouds.
        - Real-time visualization from onboard sampling sensor via GCS.
        - Download of full data after flight to enhance plume modeling and reporting of airborne particulates.
- sUAS #4:
    - VLOS or EVLOS operations with Part 107 and SGI waivers.
    - Provide real-time EO data during capture of imagery and LiDAR data to develop mosaiced mapping imagery and 3D models.

  - Operational area to be located ahead of likely fire spread in order to support fire spread modeling.

2.7 Technology Evaluation

Disasters are unpredictable in timing, scale, and impact, making systematic organization and advanced technologies critical for efficient response. A review of advanced technologies in emergency management and disaster response are summarized below.

2.7.1 Artificial Intelligence (AI)

- AI can process information, analyze emergency calls, and perform predictive analytics.
- Examples include IBM Watson's speech-to-text analytics for 911 calls and One Concern's disaster assessment platform.
- AI has helped cities like Memphis reduce emergency service costs significantly.

2.7.2 Internet of Things (IoT)

- IoT involves networks of sensors and software for real-time data collection and communication.
- Used in disaster management to monitor environmental conditions and inform the public.
- Example: Rio de Janeiro's ‘Rio Operations Center’ monitors weather, traffic, and social media during emergencies.

2.7.3 Blockchain

- Blockchain promotes transparency and coordination in financial transactions and information exchanges during emergencies.
- Center for Disease Control and Prevention (CDC) is piloting blockchain for public health surveillance data in disaster relief.
- Provides an enduring record of resource allocation accessible to all parties involved.

2.7.4 Robots (including Unmanned Aerial Vehicle (UAVs))

- Robots and UAVs are used in dangerous emergency situations, such as search-and-rescue operations.
- UAVs have been deployed in various disaster scenarios, including Hurricane Katrina, to deliver medical supplies and assess conditions.
- Challenges include coordination, standardization, scalability, proper use, and training personnel.

Data collection using robots also presents several challenges and considerations:

- Ethics and Privacy: Issues include data privacy, ethical concerns in decision-making, and the potential misuse of personal information.
- Infrastructure and Volume: Real-time data collection is limited by infrastructure, and large-scale disasters can overwhelm data storage and communication systems.
- Data Accuracy and Validity: Challenges include validating real-time data, managing different data types, and preventing the spread of false information.

2.7.5 Blue UAS

Review into advanced technologies led to an investigation into the Blue UAS process. The US Army banned Chinese drones in 2017 due to cybersecurity concerns, followed by similar bans from other military services and federal agencies. The FY20 NDAA codified this ban into law, prohibiting the procurement and operation of Chinese-made UAS and related equipment. The Blue sUAS project is managed by the Department of Defense Innovation Unit (DIU), which was developed to ensure cybersecurity and compliance with legal bans during procurement of secure, non-commercial drones for military use.

Surveys indicated that first responders want to utilize the technology and are not as concerned about the Blue UAS process. As industry, driven by the Federal Government and Department of Defense, continues to incorporate Blue UAS, more will be available to first responders. Research within A28 did not indicate a separate or even supported attempt to require these at the local, state level or in the civil sector. Requirements will evolve as Blue UAS capabilities continue to mature.

2.7.6 Coordination

RID and drone detection were mentioned as technologies that could improve coordination. One idea that surfaced is the development of an online portal in which UAS operators involved in disaster response could upload their flight plans. Once the mission is complete, the area for which they acquired data along with information on the data products. Researchers were surprised to find that on the Federal Emergency Management Agency (FEMA) remote sensing calls for Hurricane Ida, the UAS collection deck was never presented, only occupied aircraft and satellite collections were shared. A lack of understanding about what UAS operations are occurring and what data are being acquired can result in poor coordination, gaps in coverage, and overlaps in coverage. There is a clear need for a comprehensive approach to remote sensing collection management, similar to the approach employed by the military.

2.8 Conclusions

A28 laid the groundwork for the project by identifying potential UAS applications across a broad range of disaster scenarios, both natural and human made. The key outcomes of A28 include:

- **Comprehensive Disaster Scenario Analysis:** A28 explored UAS applications in 38 diverse disaster scenarios, enabling the identification of common challenges and unique opportunities for each type of event.
- **Development of Initial CONOPs:** Tailored CONOPs were developed for various disaster scenarios, providing initial guidance for UAS operations and risk mitigation. These initial documents were instrumental in shaping the subsequent A52 project.
- **Identification of Standardization Needs:** A28 revealed a significant disparity in UAS knowledge, expertise, and training across different organizations, highlighting the need for standardization and the development of minimal operational proficiency standards.

The following sections summarize the comprehensive conclusions related to roles and coordination between agencies, regulations, technological capabilities, and training/certification.

2.8.1 Agency Coordination, Roles, and Needs

The value of effective airspace coordination was the most important lesson learned from the use case demonstrations. The research found that during disasters, when the airspace was uncoordinated, it resulted in the grounding of UAS platforms, often for days. This substantially curtailed effective implementation designed to save lives and speed recovery.

- Effective coordination must include all entities operating in the airspace, not just federal agencies.
- Stakeholders should include state and local governments, tribal governments, utilities, insurance agencies, volunteers, academic institutions, the media, and the general public.
    - Local governments are always involved in disaster response.
    - State engagement varies based on disaster size, regulations, and local capabilities. Some states have more active roles, while others depend on local authorities.
    - Federally recognized tribes manage their land during disasters, coordinating external support.
- Plans should designate a single entity or individual responsible for airspace coordination.
- Organizations should conduct regular integration exercises to ensure smooth operations during disasters.
- There is a need for federal-level guidance and support for these coordination activities.

It is noted that some agencies, like wildland firefighting, have extensive FAA coordination, while others, especially local governments and private entities, have little to none. Agencies with limited FAA experience need training, exercises, and dedicated FAA liaisons during disasters. Federal and state agencies often have established CONOPS and Standard Operation Procedures (SOPs), while many local entities lack them. Organizations lacking CONOPS and SOPs need them to enhance UAS disaster response. These CONOPS and SOPs should address data security, retention, and privacy.

2.8.2 UAS Capabilities and Limitations

There are no single characteristics that define the optimum UAS for disaster preparedness. The experience of the operator, data and information needs, safety, equipment cost, and airspace coordination, all factor into UAS platform selection. In many cases, the optimum UAS will be the one that the operator is most familiar with, fits into their budget, and can meet the minimum information requirements in the timeliest manner with the least risk.

UAS can replicate most crewed-aircraft data collection missions, including damage assessment, search and rescue, risk assessment, and situational awareness.

- Advantages:
    - Lower risk to pilots and passengers.
    - Less expensive to operate and acquire.
    - Faster training and operational readiness for UAS pilots.
    - Greater flexibility in launch and landing locations.
- Limitations:
    - Restricted altitude under FAA rules without a waiver.

    - Limited operation in adverse weather conditions.
    - Short battery life (35-45 minutes).
    - Limited ability to transport objects, people, or animals.

However, there are missions that UAS cannot yet replace, including:

- sUAS cannot transport people or animals.
- sUAS are not yet viable for routine deliveries, though some use sUAS for specific tasks like controlled burns.
- Heavy-lift capabilities of manned aircraft required for fire suppression are unlikely to be replicated by UAS in the near future.

The major risks of operating UAS during disasters include system failures that could strike personnel and in-flight collisions with occupied aircraft. Mitigations involve minimizing flights over people and ensuring effective airspace coordination, often overseen by an Air Boss. The wildfire-fighting community excels in airspace management due to regular practice and exercises.

2.8.3 Regulations

The results of this project indicate that Part 107 are the primary framework in which sUAS are operated for disaster and emergency response, with public agencies also operating under a Part 91 COA to a lesser degree.

Federal Agencies are generally well-versed with emergency COA and SGI processes, though local governments and private sector entities are more likely to lack familiarity and often find the waiver process daunting. In the short term, peer-to-peer exchanges may be effective for disseminating information and best practices related to these processes, including the development of the comprehensive risk assessments needed to balance waiver risks with operational risks.

Waivers from § 107.31 – Visual Line of Sight Aircraft Operation and § 107.39 – Operation over human beings were identified as the most commonly required waivers during emergency response. The need for BVLOS waivers was ranked as the highest need, especially for large scale events and in wildland firefighting. A waiver to allow Operations Over People (OOP) was identified as critical for efficient sUAS operations during emergencies and disasters occurring in urban or populated areas.

With increased sUAS deployment expected during future disasters and emergencies, it is expected that strain will increase on the waiver process due to competing requests. Technological advancements such as Remote ID and Drone Detection may reduce the need for some waivers, especially for BVLOS operations occurring in rural and sparsely populated areas. However, it is noted that technology should complement, not replace, effective planning and coordination.

2.8.4 Certifications and Training

Clear gaps were identified in relation to the certification and training of personnel and organizations involved in emergency and disaster response, where UAS may be operated. The FAA Part 107 License is to date the only minimum requirement for disaster UAS pilots, but it is insufficient as it covers only basic knowledge without practical components. With no widely accepted standard for disaster UAS pilot training or certification, it is expected that challenges will continue to arise in assessing expertise during disasters. It is recommended that development of a standardized program or credential for UAS disaster response knowledge would ensure consistent expertise among pilots and enhance the safe integration of sUAS into the NAS during emergencies.

3 OUTCOMES OF PHASE II (A52)

3.1 Overview of Research Phase

The ASSURE A52 Phase II project, initiated by the FAA, was designed to evaluate the role of UAS in disaster preparedness and response, focusing on how UAS can be integrated into the NAS. The primary objective of this research was to enhance disaster response capabilities by identifying the strengths and limitations of UAS in various disaster scenarios and establishing best practices for their deployment in real-world emergencies. This phase built upon the "Beyond Part 107" document developed in Phase I to assist first responders in understanding UAS roles and limitations during disaster response.

The ASSURE A52 framework aimed to understand how UAS can reduce response times, improve agency coordination, and provide real-time data to support decision-making during disasters. The research covered a broad range of disaster types, including hurricanes, wildfires, pandemics, oil spills, and train derailments. Through this work, the project sought to address critical questions such as identifying best practices for UAS integration in disaster response, determining how operations can be standardized across various disaster types, and understanding the regulatory changes needed for rapid UAS deployment.

To address these questions, the ASSURE A52 team conducted 29 events, including mock demonstrations, workshops, and functional exercises across the US. These events tested UAS operations in realistic disaster settings, from hurricanes in Alabama to medical supply deliveries during pandemics in Alaska, and real-time flooding response in Vermont. The methodology involved detailed pre-event planning for safe UAS deployment, simulations in challenging environments, multi-agency coordination, and post-event analysis to gain insights into UAS performance and operational challenges.

A52 identified the next steps for Phase III that include refining the regulatory structure to create emergency and event specific guidelines, consistent standards for UAS operations and data collection, emphasis on multi-agency collaboration to standardize training, and engaging further in industry partnerships.

3.2 Mock Events and Demonstrations

3.2.1 Weather

3.2.1.1 Hurricane/Tornado

3.2.1.1.1 Overview

Between November 2022 and June 2023, the University of Alabama in Huntsville (UAH) conducted a progressive series of events focused on enhancing UAS-based disaster response capabilities. The initial seminar in Huntsville brought together over 40 participants from federal, state, and local agencies to review lessons from Hurricane Ian and explore the role of UAS strike teams. This was followed by a February 2023 tabletop workshop that simulated a major hurricane and flooding scenario. The workshop emphasized airborne communications in cellular dead zones and introduced different UAS roles supporting emergency operations. These sessions provided foundational knowledge and planning strategies for more complex operational deployments. The seminar highlighted real-world UAS deployments and fostered collaboration across agencies. The workshop expanded on this by simulating disaster response operations using varied UAS platforms, sUAS and intermediate UAS (iUAS) for communication support, SAR, infrastructure monitoring, and flood mapping. Attendees reviewed operational checklists and contributed feedback based on previous disaster responses. Building on these efforts, the June 2023 Catastrophic UAS Remote Sensing Exercise (CURSE) functional exercise in Tallahassee brought together 63 agencies for hands-on UAS deployment across multiple mission sets. UAH fielded two strike teams to perform tasks like damage assessment and SAR, integrating with Incident Command System (ICS) protocols and collaborating with FEMA's Remote Sensing Cell. This final exercise operationalized previous planning efforts and laid the groundwork for future interagency coordination and CURSE 2024.

Key themes from these events include: lack of airspace coordination and deconfliction, the need for standard operating procedures, mission planning and communication across multiple agencies (simplified communication channels, rigorous use of checklists, and disciplined role definitions were universally recommended), trained personnel for UAS air traffic control, communication protocols and integrating Geographic Information System (GIS) and the use of diverse UAS platforms—fixed-wing, multirotor, tethered, and standardized data security measures.

3.2.1.1.2 Lessons Learned

These events highlight the value of selecting the right UAS platform for the mission, considering flight endurance, payload requirements, and weather resistance. A common theme was for better inter-crew coordination and real-time task deconfliction to prevent operational overlaps and ensure the best-suited asset is assigned to each task. Simplified, structured communication was recommended, particularly when working with unfamiliar or diverse teams. A recurring issue is the presence of untrained or unfamiliar operators in high-stress environments, contributing to a chaotic "Wild West" atmosphere and posing risks to safety and mission success. Lastly, comprehensive training, including mission planning, platform familiarization, and regulatory knowledge, is essential to ensure readiness and reduce operational risks during actual emergency deployments. Recommendations from these events include: all personnel should go through emergency medical service training beforehand, checklists are crucial (site survey, mission planning, deployment, pre-/post-flight), and simplifying communication.

3.2.1.2 Flooding

3.2.1.2.1 Overview

The objectives of the two flood response events conducted by the University of Vermont (UVM) focused on evaluating and applying UAS technology for flood monitoring and emergency response. A March 24, 2023, drill in Starksboro aimed to test UAS mapping capabilities under flood conditions, specifically assessing flight procedures, sensor performance, data processing workflows, and the ability to capture high-water levels for visualization and analysis. On July 11, 2023, a functional exercise in Montpelier was conducted during a federally declared disaster and focused on acquiring high-resolution imagery to document flood impacts, support situational awareness for rescue operations, aid in geospatial damage assessments, and contribute to federal disaster declaration documentation and future resiliency planning. Both events emphasized the importance of rapid data collection, operational readiness, and the value of UAS in enhancing flood response and preparedness.

3.2.1.2.2 March 2023 Functional Exercise

The drill demonstrated that small multirotor UAS with live video capabilities are highly effective for quickly assessing flood conditions and guiding mapping missions. However, capturing oblique images in raw uncompressed formats proved inefficient due to large file sizes and limited compatibility, making Joint Photographic Experts Group files (JPEG or JPG) the preferred format for rapid sharing. Forecasting flood conditions based solely on hydrographs was found to be unreliable, complicating the timing of UAS deployments. Thermal imaging added minimal value in near-freezing conditions and significantly reduced flight efficiency due to sensor limitations, increased weight, and longer setup times. The use of custom pre-flight checklists tailored to specific platforms and sensors helped reduce human error in high-stress environments. Offline access to basemaps and elevation data was recommended to avoid reliance on internet connectivity during field operations. High-accuracy Global Positioning System (GPS) corrections such as Real-Time Kinematic (RTK) or Post-Processed Kinematic (PPK) were encouraged to improve orthoimagery precision. Finally, localized processing of large datasets required high-performance computing resources, and ArcGIS Online was identified as an effective platform for sharing processed imagery, though not feasible during mobile operations.

3.2.1.2.3 July 2023 Flood Response

The findings from the Flood Response Functional Exercise conducted on July 11, 2023, in Montpelier, Vermont, highlight the critical importance of coordinated communication, operational readiness, and interagency collaboration in large-scale UAS deployments during disaster response. Internally, UVM's use of multiple communication tools and daily briefings ensured team alignment and adaptability. Externally, pre-established relationships with state and federal agencies, including the Vermont Agency of Transportation (VTrans), Vermont State Police, Vermont Center for Geographic Information (VCGI), and FEMA, enabled efficient tasking, data sharing, and regulatory compliance, particularly through the FAA's SGI process. Operationally, the exercise emphasized the value of standardized procedures, pre-tested equipment, and the role of a dedicated response coordinator and data manager to streamline logistics and data flow. The use of fixed-wing, OOP-compliant UAS platforms proved highly effective for mapping large urban flood zones, while preliminary manual flights with multirotor drones enhanced situational awareness and mission planning. The exercise also demonstrated the importance of real-time weather monitoring, flexible mission planning, and the ability to rapidly process and disseminate orthoimagery and oblique visuals to support FEMA's damage assessments and public communication. Overall, the exercise underscored that success in UAS-based disaster response hinges on preparedness, interoperability, and the ability to transform aerial data into actionable insights.

3.2.1.2.4 Lessons Learned

These events demonstrated that UAS technology is highly effective for rapid flood assessment, situational awareness, and disaster documentation, provided there is strong operational readiness, interagency coordination, and adaptable workflows. Key lessons included the importance of using efficient image formats, reliable GPS corrections, offline data access, and custom checklists to reduce errors. Challenges such as unreliable flood forecasting and limited thermal imaging utility were noted, while the value of standardized procedures, real-time communication, and flexible mission planning was emphasized. Overall, success hinged on preparedness, interoperability, and the ability to quickly transform aerial data into actionable insights.

3.2.1.3 Earthquake

3.2.1.3.1 Overview

The Earthquake with Tsunami Seminar and Workshop/Tabletop aimed to showcase the use case of a major earthquake in South Central Alaska causing a tsunami warning and impacting a smaller community, to the wider UAS and disaster response community, and gather feedback on the developed use case. Both events involved presentations, followed by Mentimeter surveys to assess attendees' knowledge and capabilities regarding UAS applications in this context. The seminar was held online via Zoom with 30 attendees, while the workshop was a one-day event at University of Alaska Fairbanks (UAF) with a mix of in-person and online participants, providing opportunities for feedback and discussion on the use case and its execution.

Both events emphasized that UAS can provide long-term high-altitude observations, continued night-time operations, rapid response capabilities, and access to at-risk locations for precise mapping and situational awareness. Thermal and visible cameras, LiDAR sensors, and airborne communication platforms were all useful to assess the earthquake with tsunami events. The seminar and workshop underscored the importance of knowing available UAS resources, running test cases, and integrating UAS into local, state, and regional incident command structures. Additionally, the need for detailed checklists, safety equipment, and permissions for BVLOS operations were discussed to ensure effective and safe UAS deployment during disaster events.

Common themes between the seminar and workshop included the necessity for real-time situational awareness, post-flight mapping, and 3D modeling to support SAR operations and infrastructure assessment. Both events highlighted the importance of communication and coordination among response teams, ensuring that UAS operations do not hinder other emergency activities. Recommendations included having a database of Part 107 pilots for SAR, periodic training, and basic ICS and Emergency Medical Service (EMS) training for all UAS operators. The findings also pointed out the need for archiving metadata, assessing pilot fatigue, and ensuring safe flight operations amidst potential hazards like aftershocks and multiple tsunami waves. These insights aim to enhance the effectiveness of UAS in disaster response and improve decision-making processes during earthquake and tsunami events.

3.2.1.3.2 Lessons Learned

The lessons learned emphasized the importance of integrating UAS into event response protocols, following local, state, and regional incident command structures. Attendees highlighted the need for local UAS operators to support response efforts, especially in areas like Anchorage where drone programs may not be established. Key topics raised included the necessity for FEMA ICS training for drone flight teams to ensure they understand protocols and workflows during an event, and the importance of assessing flight team fatigue to maintain safety and effectiveness. Additionally, flight teams must demonstrate experience in multi-aircraft environments to operate safely in busy airspace and support existing operations without posing risks.

3.2.1.4 Landslide

3.2.1.4.1 Overview

UVM conducted a landslide drill to explore the integration of sUAS for landslides, which are common in Vermont. UAS offers significant benefits, such as collecting real-time information from inaccessible or dangerous areas and evaluating land surface changes over time, aiding hazard assessment and risk mitigation. Challenges such as high topographic relief, remote locations, inclement weather, and sparse infrastructure must be addressed to fully realize these benefits. The drill aimed to operate UAS to collect oblique images, true-color mapping imagery, and LiDAR elevation data in response to landslide activity, creating orthomosaic maps and accurate elevation models. Additionally, the drill sought to identify challenges and opportunities in integrating UAS into landslide response efforts.

The drill was at Smugglers Notch, Vermont, to address the natural challenges, including unstable alpine weather, steep vertical terrain, and remote access limitations often found in landslide events. Pre-flight preparations emphasized careful weather monitoring and a decision-making plan to ensure sUAS operations could proceed safely despite unpredictable conditions like downdrafts and visibility changes. The drill was strategically scheduled for fall 2023 during leaf-off conditions to maximize visibility for drone operations. Manual oblique imagery and video collection were performed using multirotor UAS with first-person view (FPV) perspective for real-time situational awareness. Automated true-color mapping missions and LiDAR data collection were performed with a medium-lift multirotor platform. These combined approaches allowed for high-quality 3D mapping despite the site's difficult topography and environmental conditions.

The landslide drill at Smugglers Notch and a staging area was selected to maximize safety and visibility, with visual observers (VOs) and public engagement protocols in place. Pre-flight checklists were completed to ensure platform readiness and weather compliance. Flight operations began with a small multirotor equipped with a LiDAR sensor; initial Global Navigation Satellite System (GNSS) connection issues due to valley topography were resolved by raising the UAS to 230ft AGL. Two LiDAR flights were conducted, followed by true-color mapping missions and followed by manual oblique imagery and video capture using sUAS. All datasets collected from this exercise were processed, analyzed and then published on ArcGIS Online to ensure the usability for in-depth geological analyses by agencies and the public alike.

The landslide drill demonstrated that UAS platforms with gimbals capable of multiple-axis rotation are highly effective for collecting detailed imagery in steep and complex terrains. Flexible flight planning, including the use of oblique camera angles and multiple flight plans at varying angles, greatly improved data quality.

3.2.1.4.2 Lessons Learned

Key findings emphasized the value of LiDAR over photogrammetry in capturing detailed elevation data, the importance of maintaining Standard Operating Procedures (SOP) to avoid data loss, and the need for Smart AGL terrain-following to enhance safety and regulatory compliance. Additionally, operating in alpine environments highlighted the challenges of unpredictable weather, GPS signal loss, and the need for backup positioning methods like PPK corrections using Continuously Operating Reference Stations (CORS). Carrying out higher altitude orthoimagery flights first helped the team familiarize themselves with site-specific visibility challenges before conducting lower-altitude LiDAR collections.

Based on these findings, recommendations include selecting UAS platforms that support gimbal flexibility for oblique imaging, conducting multiple angled flight missions to enhance mapping results, and preparing for RTK or PPK challenges in complex terrains. Teams should develop clear SOPs, establish contingency plans for weather and GPS interruptions, and utilize terrain-aware flight planning tools like Smart AGL. The drill also answered several research questions by confirming that multirotor UAS platforms with swappable payloads are ideal for landslide monitoring, that close coordination with stakeholders improves operational success, and that small UAS outperform manned aircraft in high-detail, complex terrain data collection. These insights highlight how UAS-based approaches can significantly advance landslide response and long-term hazard monitoring efforts.

Lessons learned include that UAS flights collecting LiDAR and orthoimagery are highly valuable for both immediate landslide response and long-term hazard assessment, but operations in steep, complex terrain require careful planning and risk mitigation. Rapid sUAS deployment after a landslide is critical for assessing imminent risks, providing vital information on evacuation routes and unstable areas. Long-term risk assessment depends on repeat surveys over time, which help scientists track landscape changes, create hazard maps, and predict future rockfall events more accurately.

3.2.1.5 Volcano

3.2.1.5.1 Overview

The Volcanic Eruption Seminar aimed to showcase the use case of a volcanic eruption from Mt. Spurr in Alaska and its impact on Anchorage and South-Central Alaska to the wider UAS and disaster response community, gathering feedback on the developed use case. Held online via Zoom, the seminar involved 46 sign-ups and 32 attendees, who completed a Mentimeter survey on their UAS capabilities and knowledge. Similarly, the Volcanic Eruption Workshop/Tabletop, aimed to gather feedback on the use case through a day-long workshop at UAF, involving both in-person and online attendees, and resulted in updated CONOPs for a potential Mt. Redoubt eruption based on participant recommendations.

The Volcanic Eruption Seminar and Workshop/Tabletop both highlighted the critical role of UAS in volcanic eruption response. Key findings from both events emphasized that no single UAS can support all aspects of the volcanic use case. sUAS can provide rapid response observational data from hard-to-reach locations, while lUAS can offer high-altitude observations and sample volcanic plumes. Both events underscored the importance of real-time situational awareness, with UAS providing thermal and visible data to prevent ground teams from being put at risk. Volcanic ash may limit UAS operations to BVLOS, therefore FAA input would be necessary to obtain a waiver. Additionally, the need for TFRs to ensure safe airspace coordination during volcanic events was discussed.

Common themes between the seminar and workshop included the necessity for detailed checklists and safety equipment for flight crews, given the hazardous volcanic materials they might encounter. Both events recommended that UAS should support both day and night operations and emphasize the importance of communication and coordination among all response teams. The findings also pointed out the need for real-time and post-mission data collection, including visible and thermal feeds, ash and gas sampling, and 3D modeling of eruptive products. It is also important to note the corrosive environment and high temperatures associated with volcanic eruptions and events.

3.2.1.5.2 Lessons Learned

The lessons learned from the Volcanic Eruption Seminar and Workshop/Tabletop emphasized the importance of integrating UAS into event response protocols, following local ICS and regional eruption response plans, and ensuring effective communication among responsible agencies. Key topics raised included the necessity for detailed checklists, safety equipment, and permissions for BVLOS operations and flights over people. The experience of attendees highlighted the need for flight teams to have knowledge of the flight environment, ongoing volcanic risks, and the ability to support other operations without hindrance. Additionally, considerations for night operations, multi-flight coordination, incorporating both lUAS and sUAS to accurately capture the entire event, and the impact of volcanic hazards on airframes and sensors were discussed, underscoring the critical role of UAS in enhancing situational awareness and decision-making during volcanic events.

3.2.2 Technological

3.2.2.1 Pandemic

3.2.2.1.1 Overview

The objectives of the pandemic-related UAS events focused on exploring and demonstrating the viability of unmanned aerial systems for medical supply delivery during emergency scenarios. The initial seminar on medical delivery between rural communities aimed to showcase a use case involving supply transport to areas inaccessible by road or river during the early COVID-19 pandemic, while soliciting feedback from the broader UAS and disaster response community. Similarly, the seminar on delivery between a major medical hub and a rural community presented another use case with the same constraints and gathered stakeholder input. The functional exercise on September 8, 2023, tested an iUAS delivering medical supplies from Fairbanks to Nenana, Alaska, under pandemic conditions that rendered traditional transport methods inoperable, validating both outbound and return flight operations in controlled airspace. A subsequent exercise on September 23, 2023, used a sUAS for intra-community deliveries in Bethel, Alaska, aiming to demonstrate how local Part 107 pilots could collaborate with health organizations to support community logistics during pandemics. Key goals included identifying suitable delivery sites, using standardized safety checklists, and proving that community-based sUAS operations could play a vital role in future emergency responses.

The findings from the four pandemic-related UAS medical delivery events—two seminars and two functional exercises—reveal several consistent themes and operational insights. Across all events, the importance of coordination between medical facilities, often within the same organization, was emphasized, particularly in ensuring smooth logistics and regulatory compliance. A recurring theme was the need for local capacity: having trained Part 107-certified pilots and medical personnel in rural communities is critical, especially when external access is limited during a pandemic. Weather assessment and operational flexibility were highlighted as essential, with teams advised to conduct early and ongoing weather checks and be prepared to delay or adapt missions as needed. Communication protocols, including standardized terminology and clear roles for pilots and observers, were also seen as vital for safety and efficiency. Both sUAS and iUAS were considered effective depending on the mission scope, with aircraft selection based on range, payload, and environmental conditions. Additionally, cybersecurity, data integrity, and adherence to FAA regulations (e.g., RID) were noted as key concerns. Training for medical staff on UAS procedures and the integration of UAS into routine logistics were recommended to enhance preparedness. Overall, the events underscored the value of UAS in bridging logistical gaps in remote areas, while identifying the need for robust planning, local partnerships, and regulatory awareness.

3.2.2.1.2 Lessons Learned

Across the four pandemic-related medical delivery use cases, several common themes emerged. A consistent lesson was the importance of training medical personnel, especially in rural communities, on the capabilities and limitations of sUAS/iUAS, including how to handle cargo and support flight operations. Effective coordination between sending and receiving medical facilities, often within the same organization, was also emphasized, along with the need for clear communication protocols and defined roles for flight crews. Weather assessment was critical, with teams advised to monitor conditions closely and be prepared to delay or cancel flights if necessary. Equipment checks during delays and strict adherence to operational checklists were highlighted as best practices. Additionally, the exercises underscored the value of involving nursing and medical students in demonstrations and maintaining a stakeholder contact database to streamline communication. These lessons collectively point to the need for robust planning, interagency collaboration, and community engagement to ensure safe, efficient, and impactful drone-based medical delivery in remote areas.

3.2.2.2 Oil Spill

3.2.2.2.1 Overview

The Oil Spill Seminar and Workshop/Tabletop aimed to showcase the use case of an oil spill from an oil terminal in Alaska, impacting surrounding land surfaces and spreading across the Bay, to the wider UAS and disaster response community, and gather feedback on the developed use case. Both events involved presentations, followed by surveys to assess attendees' knowledge and capabilities regarding UAS applications in this context. The seminar was held online via Zoom with 44 attendees, while the workshop was a one-day event at UAF with a mix of in-person and online participants, providing opportunities for feedback and discussion on the use case and its execution. Outcomes from the workshop led to the development of an additional CONOPs focusing on a smaller oil spill from the Trans-Alaska Pipeline System in Alaska.

The findings from the Oil Spill Seminar and Workshop/Tabletop emphasized that no single UAS can support all aspects of the use case, with large UAS providing high-altitude observations and small UAS offering detailed mapping and situational awareness through thermal, visible, and LiDAR sensors. Key technologies mentioned include herder/burner tools for spill mitigation and AI or Machine Learning (ML) for real-time data interpretation. The seminar and workshop underscored the importance of rapid data access, coordination among response teams, and awareness of local wildlife and cultural heritage sites to ensure safe and effective operations.

There is a need for real-time situational awareness, post-flight mapping, and 3D modeling to support decision-making and infrastructure assessment. Both events highlighted the importance of communication and coordination among response teams, ensuring that UAS operations do not hinder other emergency activities. Recommendations included having FEMA ICS training for drone teams, metadata archiving, and integrating UAS into local, state, and regional incident command structures. The findings also pointed out the need for backup sites, assessing pilot fatigue, and ensuring safe flight operations amidst potential hazards like wildlife interference and changing weather conditions. There is also a need for a multirotor UAS with a gas sensor to effectively respond and collect data for oil spill events.

3.2.2.2.2 Lessons Learned

The oil spill use case emphasized the importance of operating under a full incident command structure with a State Emergency Operations Center (SEOC). Effective communication between flight crews and the lead for air operations at the SEOC is crucial to ensure awareness of all airborne operations, including both crewed and uncrewed systems. Given the complexity of the response, with multiple UAS flight crews, other airborne assets, and ground teams, it is essential for all UAS crews to have comprehensive flight checklists, obtain all necessary permits for defined flight patterns, and maintain communication with central operations before and after each flight to minimize any issues and ensure safe and effective operations.

3.2.2.3 Train Derailment

3.2.2.3.1 Overview

Between March 2023 and April 2024, UVM, in collaboration with state and local agencies, organized a series of seminars and workshops to plan and execute a mock train derailment response exercise using sUAS. The initiative began with a seminar on March 29, 2023, introducing the exercise concept and gathering feedback from stakeholders such as VTrans and UVM Emergency Management. A workshop on May 18, 2023, focused on defining roles, selecting a location, and outlining logistics. A third workshop later in 2023 addressed risk mitigation, airspace coordination, and team responsibilities.

Following delays due to the 2023 Vermont flood, planning resumed with a February 1, 2024, seminar to re-engage participants and update the timeline. A March 12 workshop ensured all final preparations were in place, including equipment, support, and methods for capturing lessons learned. The final workshop on March 28 reviewed plans with all stakeholders and finalized documentation and materials. The process culminated in a functional exercise on April 2, 2024, simulating a train derailment near Burlington, Vermont. Multiple agencies deployed UAS for search and rescue, hazard monitoring, and mapping. Coordination, communication, and data-sharing processes were tested, reinforcing UAS as a valuable tool for multi-agency emergency response.

The train derailment mock exercise events were centered around the following scenario:

"Vermont Agency of Transportation has been notified that a freight train derailed along the Burlington Vermont Waterfront near the Island Bike Trail. Information is limited as to the extent of damage to infrastructure, active fire, injuries of those directly or indirectly involved, missing persons, or hazardous materials or liquid leaking from the carts into the local environment. Vermont Agency of Transportation requests UAS support from local and state agency first responders and additional groups with UAS capabilities. Following local and federal regulations pertaining to UAS operations in controlled airspace, the UAS Air Boss must organize, manage,

and deploy multiple UAS assets to obtain unknown information, later to be dispersed to impacted stakeholders and investigating authorities."

The events to prepare consistently followed a structured, collaborative, and iterative process. Common elements across all seminars and workshops included the use of PowerPoint presentations to align participants on goals, open discussions to gather input and address concerns, and thorough planning of key elements such as location selection, airspace coordination, team roles, and UAS mission profiles. All events emphasized clear communication protocols, with the designation of a UAS Air Boss to manage airspace and radio communication. Safety considerations, such as site mapping, buffer zones, and use of VOs, were recurrent themes, as were the approval processes for Low Altitude Authorization and Notification Capability (LAANC) authorization and backup plans for equipment and weather. Teams consistently coordinated around data collection, processing, and dissemination, with UVM and VCGI managing data workflows to mirror real-world emergency responses. Repeated planning sessions built progressively toward the final exercise, which tested these logistics in complex, multi-UAS scenarios.

One central theme was the need for clear protocols for mobilizing UAS teams, including coordination with Emergency Operations Center (EOCs) and standardized procedures for tasking, airspace authorization (via LAANC), and real-time communication. The designation of a UAS Air Boss proved essential for managing multiple operations, though further definition of qualifications, roles, and the addition of an Assistant Air Boss were widely recommended. Airspace coordination, including partitioning and use of vertical buffers, was a repeated concern, especially in Class C zones or crowded environments. Live streaming and mapping were confirmed as vital mission profiles, and the importance of matching platforms/sensors to mission needs was emphasized. Data collection, processing, and dissemination were consistently noted as critical yet underdeveloped elements needing streamlined workflows and field-based tools. Additionally, the importance of public interaction management, safety planning, and the integration of feedback through hotwashes and lessons-learned documentation was underscored. Overall, the findings emphasized the value of cross-agency collaboration, scenario-based planning, and adaptive logistics to enhance UAS effectiveness in disaster response.

3.2.2.3.2 Lessons Learned

Across seminars and workshops, it was identified that there is a need for clear protocols for UAS support requests, including guidance on what types of data are needed and which organizations can provide them. The use of multiple mission profiles—such as live stream video for real-time awareness, SAR operations, and mapping (EO, multispectral, LiDAR)—was affirmed as essential for comprehensive response. A UAS Air Boss role, with well-defined responsibilities and support from an Assistant Air Boss, was critical for safely managing multiple simultaneous operations, airspace partitioning, and standardized communication. Mitigating risks such as inclement weather, airspace conflicts, and non-participant intrusion were emphasized using VOs, clear signage, geo-fencing, and pre-authorized platforms. Collaboration and coordination with ICS, EOCs, and regional partners were highlighted as vital for smooth tasking and integration into broader emergency response. Finally, operational readiness hinged on pre-planned equipment checklists, communication protocols, and data sharing workflows, reinforcing that detailed preparation and cross-agency alignment are key to safe and effective UAS disaster response.

3.2.2.4 Terrorism

3.2.2.4.1 Overview

A seminar and drill were conducted and involved HSV hosting the inaugural landing of Sierra Nevada Corporation's Dream Chaser spacecraft, which expected to draw large crowds around the Airport Operations Area (AOA). The event included a multi-agency public safety effort with local, state, and federal law enforcement, fire/rescue, and emergency medical personnel on standby. Multiple authorized UAS were to provide situational awareness for public safety and media coverage, while unauthorized UAS incursions led to safety incidents, including injuries and a small battery fire. The Airport Terrorism Seminar aimed to discuss the risks of UAS incursions at airports and special aviation events, focusing on detection and mitigation technologies in low-altitude airspace management. The tabletop drill simulated real-world UAS incursion scenarios and gathered feedback on using other UAS assets to mitigate threats. The drill was hosted on the last day of the "2023 Future Proof UAS & Counter-UAS (C-UAS) Summit". Over 250 attendees were present from local/state/federal government agencies and industry. The seminar was advertised daily at the summit and took advantage of the existing event infrastructure to host the drill. The main objective of this drill was to step through a real-world scenario of UAS incursion on active airspace during a special event and to elicit feedback from participants on how the use of other UAS assets may help alleviate the threat. The seminar included a presentation during one of the UAH talking sessions and introduced a tabletop drill with local law enforcement in Huntsville, Alabama, aimed at developing "Drone First Responder" programs.

The drill was conducted at the UAS/C-UAS Test Facility west of HSV, under a large tent from the previous day's event. Participants, including experienced UAS operators from Huntsville Civic organization, engaged in discussions and critiques. The drill involved placing color-coded pins on the map to represent various elements and responding to unforeseen "injects" such as unauthorized UAS causing safety incidents. Follow-up activities included further demonstrations of C-UAS technologies and engagement with local law enforcement to develop drone first responder capabilities.

The Airport Terrorism Seminar highlighted that drones are useful in responding to terrorist events, particularly for damage assessment, SAR, and forensic image gathering, but not in preventing such attacks due to the challenges of maintaining permanent airborne surveillance in sensitive airport airspace. The seminar emphasized the specific challenges posed by restricted airspace around airports and the importance of close coordination with ATC during emergencies. sUAS multirotor aircraft were deemed best for all emergency response CONOPs. Recommendations included refining processes, standards, policies, and procedures through collaboration among various agencies and developing technologies like UAS Traffic Management (UTM) to enhance disaster response capabilities.

Key findings of the drill exercise were that UAS was well-suited for traffic monitoring, transporting medical supplies in congested environments, and providing situational awareness at large-scale events. Huntsville local law enforcement emphasized the importance of thorough preparatory efforts, including traffic management and airspace sterilization before the event. A surprising suggestion was to reduce UAS usage during the event to rapidly identify flight violations in restricted airspace, allowing law enforcement to respond effectively.

Specific use cases included employing sUAS for traffic monitoring and medical supply transport, with mitigation strategies to avoid flying over people and using qualified Part 107 trained UAS pilots. All CONOPs defined in the drill involved sUAS, typically commercial multirotors, capable of carrying high-resolution video equipment and medical supplies. Planning for such events must begin months in advance, considering remote parking, traffic management, site layout, and logistics. Brainstorming potential nefarious activities and developing a planning checklist for large public events involving drones were recommended for effective long-range planning.

3.2.2.4.2 Lessons Learned

The Airport Terrorism seminar and exercise highlighted that a more thorough site evaluation involving varied first responders would have led to a more robust strategy, including better positioning of response vehicles, observers, Very Important Persons (VIPs), and traffic flow control. Planning for crowd and traffic management is crucial, with a lockdown of the area imposed well before the event. Historical airport attacks show that UAS are not effective in preventing incidents or providing significant advance warning. However, a persistent overhead observer drone could be useful for retracing perpetrators' paths for forensic analysis, despite privacy concerns. Post-event, drones are valuable for damage assessment, search and rescue, and avoid hazards from secondary detonations and chemical threats. Over the long term, drones are beneficial for inspecting and assessing damage to infrastructure, reducing the risk to humans in unstable structures.

3.2.3 Fire

3.2.3.1 Wildland Fire

3.2.3.1.1 Overview

This event of a newly detected wildland fire from satellite data led to several different use cases where drones and UAS can operationally support the event response. There are several hazardous impacts to the surrounding landscape and infrastructure where UAS can minimize putting personnel at risk and supplementing existing assets. Events included online seminars and workshops, featuring presentations and surveys to gather feedback from the UAS and disaster response community, as well as a functional exercise involving live fire tests to assess UAS support elements in real-time conditions.

The event aimed to showcase the capabilities of UAS in supporting ground crews during prescribed burns and exploring UAS as a response tool in controlled burn scenarios. The initiative included a series of online seminars and workshops, which featured presentations and surveys to gather participant feedback. A one-day workshop was also held at the UAF campus, offering step-by-step presentations and interactive feedback sessions.

A key component of the event was a functional exercise designed to evaluate UAS support elements in real-time fire conditions. This exercise included three scenario types: the Dry Run Test, the Fire Test, and the Structure Fire Test. The Dry Run Test, conducted at the Dona Ana Fairgrounds in New Mexico, focused on testing flight systems, sensors, and equipment in a simulated mission environment. The Fire Test took place at the Jornada Research Range, New Mexico, and involved live heat sources and fire elements to assess UAS capabilities in mapping and overwatch missions. The Structure Fire Test, held at the Las Cruces Fire Department Fire

Training Facility, New Mexico, simulated a structure fire to re-test flight systems and operational procedures.

Various UAS platforms and sensor technologies were employed during these tests, including tethered and free-flight systems equipped with LiDAR, thermal, and EO sensors. Aircraft such as the Trinity Vertical Take-Off and Landing (VTOL), Matrice, Super Volo, and X-6 were used for mapping, real-time visuals, and thermal imaging. Handheld Forward-Looking Infrared (FLIR) devices were also utilized to provide ground truth measurements and evaluate sensor performance in smoke and heat conditions.

Logistical coordination was extensive, involving multiple universities and teams. Planning included setting up flight operations, ensuring safety protocols, managing equipment transport, and site setup. The final controlled burn exercise was conducted in Pontotoc, Mississippi, in collaboration with the Mississippi Forestry Commission. This required meticulous planning to ensure the burn was conducted safely and effectively, highlighting the importance of interagency coordination and preparedness in fire response scenarios.

3.2.3.1.2 Lessons Learned

Effective UAS operations in emergency response scenarios require thorough airspace coordination, including securing all necessary permissions such as COAs, BVLOS waivers, SGI approvals, and TFRs to ensure safe integration into the NAS. Real-time data access is critical; flight data should be streamed directly to ground stations and incident command centers, with post-flight data processed rapidly in the field to support timely decision-making. UAS teams must be fully integrated into local incident command structures and maintain operational readiness by holding Part 107 certifications, staying in communication with central operations, checking pilot reports, monitoring weather conditions, and consulting incident meteorologists for fire behavior forecasts. Additionally, teams should be trained in FEMA Incident Management Team (IMT)/ICS protocols to understand emergency response procedures and decision-making frameworks. Operational self-sufficiency is essential—UAS teams must demonstrate experience operating in complex airspace and hazardous environments, ensuring they are self-reliant and contribute positively to the incident command system without becoming a burden.

3.3 Risk Assessment and Mitigation

A review of outcomes from A28 and A52 events provided categorization of common risks as follows:

- Adverse Operating Conditions
    - Collision Risks: Includes terrain, structures, people, and other aircraft due to limited visibility, loss of control, or communication failures.
    - Weather-Related Risks: Sudden inclement weather, unexpected winds, and disaster-specific conditions (e.g., volcanic ash, toxic gases) can disrupt missions and endanger crews and aircraft.
    - Flight Limitations: VLOS constraints, fatigue from extended operations, and lack of synchronized timing between missions hinder effectiveness.
- Deterioration of External Systems

  - Power & Equipment Failures: Generator issues (onboard and ground-based), engine/power loss, and onboard malfunctions can ground operations or cause crashes.
  - Navigation & Communication Failures: GPS outages, loss of control links, and tracking antenna failures compromise mission safety and coordination.
  - Tethered UAS Vulnerabilities: Tether breakage or power/data loss can lead to uncontrolled flight or mission failure.
- Human Factors
  - Communication Failures: Between crew members, flight crew, ATC, and others in the airspace.
  - Human Factors: Cognitive and physiological strain, and distractions from non-crew members.
  - VO Limitations: Loss of visual contact due to extended flight times, weather, or lack of BVLOS planning.
  - Safety Over People: Potential for crashes and inability to ensure safe operations with authorized equipment.
  - Ground Operations: Access issues at sites and inability to capture data needed or deliver supplies.
- UAS Technical Issues
  - Timing & Synchronization: Lack of precise timing between multiple UAS missions prevents effective data comparison and situational analysis.
  - Airspace Management: Issues with entering restricted zones or coordinating between multiple GCS can disrupt operation.

A28 and A52 outlined mitigation strategies to the above risks as follows:

- Adverse Operating Conditions
  - Standardized Emergency Procedures: Use of Return to Base (RTB), Divert and Land Immediately (DLI), and Terminate Flight (TER) protocols are central to managing in-flight emergencies.
  - Pre-Mission Planning: Includes defining alternate landing zones, synchronizing mission timing, and assessing weather and airspace conditions.
  - VLOS Assurance: Constant communication between Pilot in Command (PIC) and VOs, with contingency plans for BVLOS operations.
  - Dynamic Response to Conditions: Real-time monitoring of weather, volcanic activity, and toxic exposure informs flight adjustments.
  - Safe Landing Protocols Over Water or Hazard Zones: Pre-identified ditch points and alternate landing sites are critical for overwater or hazardous terrain operations
- Deterioration of External Systems
  - Redundancy and Backup Systems: Backup UAS, GCS, power sources, and communication tools are essential for continuity during failures.

    - Routine Checks and Pre-Flight Briefings: Emphasis on verifying flight plans, equipment functionality, and environmental conditions before launch.
    - Fail-Safe Design: Systems are configured to loiter, land, or return home in case of GPS loss, power failure, or control link disruption.
- Human Factors
    - Crew Readiness and Rotation: Fatigue is mitigated through crew rotation, debriefs, and pre-flight fitness checks.
    - Communication Protocols: Clear, pre-briefed communication plans and backup devices (e.g., satellite phones) reduce risk of miscommunication.
    - Spectator Management: Sterile control zones and designated personnel to handle non-crew interactions ensure operational focus.
- UAS Technical Issues
    - Time Synchronization: All UAS and sensors are synchronized to UTM to ensure data comparability.
    - Inter-Agency Coordination: Shared airspace and multi-UAS operations require coordinated planning to avoid mid-air conflicts and ensure safe landings.

3.4 Procedures and Guidelines

The completion of the events executed in A52 led to several conclusions and recommendations regarding procedures for UAS in emergency response and guidelines for responders deploying this technology.

3.4.1 Disaster-Specific Regulatory Framework

- There is a need for temporary, event-specific regulations during disasters.
- These should include airspace control, especially over hobbyist and media drones, and rapid or pre-approved TFR/SGI approvals to support emergency operations.

3.4.2 Unified Privacy Standards

- A consistent set of privacy rules across local, state, and federal levels is essential.
- First responders currently face confusion due to varying privacy laws when collecting imagery.

3.4.3 Standardized Pilot Proficiency

- A Minimum Operational Proficiency Standards (MOPS) framework is proposed to assess UAS pilot skills beyond Part 107 certification.
- Key competencies include piloting skills, SAR visual acuity, airspace knowledge, risk analysis, safety practices, and familiarity with sensors and data products.

3.4.4 Cross-Cutting UAS Procedures

- UAS operations must be integrated into the ICS.
- Operators should be trained in FAA emergency procedures, risk/safety analysis, and appropriate drone selection based on mission needs.

3.4.5 Mission-Specific Aircraft Selection

- Fixed-wing drones are best for mapping, oversight, and deliveries.

- Multirotors are ideal for SAR, damage assessment, and close-range imaging.
- Aircraft choice depends on mission type, budget, and pilot skill, and should remain flexible due to rapid tech evolution.

3.5 Conclusions

A52 transitioned from theoretical analysis to practical application through 29 mock events and exercises. The key findings of A52 include:

- **Validation of UAS Utility:** The exercises confirmed the practical value of UAS in disaster response tasks, such as situational awareness, search and rescue, damage assessment, and information gathering.

- **Multi-Agency Coordination Challenges:** A52 revealed the complexities of coordinating UAS operations involving multiple stakeholders. Communication breakdowns, airspace conflicts, and inconsistent data sharing practices were observed, emphasizing the need for improved coordination mechanisms and standardized protocols.

- **Refinement of CONOPs and ORAs:** Feedback from the exercises allowed for refinement of the CONOPs and ORAs developed in A28, improving their operational relevance and addressing previously unforeseen challenges.

- **Reinforcement of Training and Standardization Needs:** A52 underscored the need for standardized training and credentialing of UAS operators, further developing the MOPS concept and highlighting its importance for interoperability.

The research produced significant findings. UAS have proven beneficial in disaster-related tasks such as oversight, search and rescue, imaging, mapping, and transporting critical goods like medical supplies. However, there is wide variation in knowledge, expertise, and training regarding UAS use across local, state, and federal organizations. The project introduced the concept of MOPS, highlighting the need for training and accreditation processes to evaluate and credential UAS operators. As UAS use in disaster exercises and real-world events increases, their utility is expected to expand further. The project also underscored the importance of Functional Exercises, where operators interacted with real or simulated environments and incident command to assess risks and adapt to changing circumstances, delivering actionable data to save lives and expedite recovery.

These findings were utilized in the structure of the following Phase III research to further refine the regulatory structure to create emergency-specific guidelines that expedite UAS deployment. Additionally, the team will develop uniform standards for UAS operations to ensure consistent data collection and usage across agencies. Multi-agency collaboration between the FAA, FEMA, and National Institute of Standards and Technology (NIST) will be key to executing standardized training for first responders, UAS operators, and agency leaders to improve interoperability during disaster response efforts. Lastly, continued industry investment in UAS technology is critical to advancing capabilities such as battery life, payload capacity, and data transmission in disaster environments. This research represents a pivotal step toward building a national framework for

UAS disaster response, ensuring that UAS technology is fully leveraged to save lives and mitigate damage in future disaster scenarios.

4 OUTCOMES OF PHASE III (A62)

4.1 Overview of Research Phase

The A11L.UAS.68: Disaster Preparedness and Emergency Response Phase III (A62) was the third phase of this long-term research initiative. Conducted from October 2022 to February 2025, A62 built upon the findings of Phases I (A28) and II (A52), continuing the exploration of UAS as tools for disaster response and recovery. Coordinated by Mississippi State University (MSU) and led by the UAH, with research partners from New Mexico State University (NMSU), UVM, North Caroline State University (NCSU), and Kansas State University (KSU), the program focused on identifying technology solutions, refining operational practices, and enhancing interagency coordination. Over the performance period, the US experienced 73 billion-dollar disasters and over 1,500 fatalities, further emphasizing the need for innovative response tools.

A62 emphasized real-world exercises and public safety engagement, ensuring that research outcomes were grounded in operational realities. The program addressed a wide range of research questions related to UAS use cases, coordination across government levels, operational risks, autonomy, cybersecurity, and integration into the NAS. It also assessed the impact of new legislation, such as the NDAA, and explored the potential benefits of a public safety pilot rating beyond Part 107. Additional research tasks focused on airworthiness, crew training, UAS incursions, and standardizing disaster action plans across agencies. The program also investigated the composition and growth of UAS fleets and coordinated with FEMA and National Wildfire Coordinating Group (NWCG) on UAS typing standards.

A62 included a targeted focus on data sharing and storage, addressing challenges in managing the vast amounts of data generated during disaster operations. Research explored the feasibility of a centralized interagency data portal, cybersecurity risks, and the development of a central database for UAS system capabilities. Metrics for evaluating UAS effectiveness in disaster scenarios were also proposed. Finally, the program prioritized continued engagement with public safety entities and international outreach, aiming to harmonize global UAS disaster response practices and incorporate lessons from international partners to improve domestic coordination.

4.2 Analysis of Technological Solutions to Enable Expanded Operations

Researching technological solutions to expand the operational capabilities of UAS, remote pilots, first responders, and emergency management coordination was the key focus of A62 Task 2.

Sub-Task 2-1 explored the use of multiple sUAS, or swarms, in disaster response and recovery. The study found that advancements in autonomous navigation and decision-making technologies now allow for coordinated operations of multiple aircraft without direct human control. Algorithms for formation management and geographic coverage can be trained to execute search and surveillance patterns and can adapt in real time based on incoming data or incident command directives.

Sub-Task 2-2 focused on the role of RID in UTM. It highlighted that the inability to rapidly identify UAS in disaster zones poses a significant risk to both authorized UAS and manned aircraft.

The study proposed a comprehensive framework for integrating RID into National Aeronautics and Space Administration's (NASA) UTM system using the Flight Information Management System (FIMS), UAS Service Suppliers, and FAA vehicle registration (14 CFR Part 47). While C-UAS technologies can detect unauthorized aircraft, their use must be carefully managed to avoid interfering with authorized operations.

Sub-Task 2-3 involved a market survey and literature review of software tools used in military and emergency management. These tools were evaluated against the six core functions of the ICS, with a focus on their application to UAS operations. The study emphasized the importance of situational awareness and information sharing, especially in chaotic, multi-agency environments. GIS were found to be a common foundation across platforms like Search & Rescue Common Operating Platform (SARCOP), Team Awareness Kit (TAK), and CALTOPO/SARTOPO. A major challenge identified was the aggregation and interpretation of large-scale data to support a Common Operating Picture (COP).

Sub-Task 2-4 examined the responsibilities of the Air Operations Branch Director (AOBD) within ICS and proposed the concept of an "Automated Air Boss." This system would automate key coordination tasks, such as submitting SGI and LAANC requests or issuing NOTAMs, to reduce the burden on human operators. The integration of AI and situational awareness tools could streamline airspace coordination and resource allocation. However, the study stressed that any automation must align with the strict decision-making hierarchy of ICS to be effective and widely adopted.

4.3 Analysis of Legislation, Policies, Procedures, and Standards

The research team explored the impact of new legislation on UAS disaster and emergency response and recovery operations. This research explored draft policies, procedures, and standards for UAS supporting disaster and emergency missions.

Sub-Task 4-1 examined the legislative impacts on UAS use in disaster response, focusing on the American Drone Security Act of 2023. This legislation restricts government agencies from using UAS from "covered foreign entities" such as China and Iran. Although exemptions exist, the process is often inconsistent, complicating procurement. The Act also mandates a study to identify gaps in domestic UAS production and aims to support agencies in acquiring compliant systems.

Sub-Task 4-2 explored UAS training for public safety personnel, emphasizing the value of specialized qualifications tailored to disaster response. The study found that such training improves safety and operational effectiveness. It highlighted the American Society for Testing and Materials (ASTM) F3379 Standard Guide for Training for Public Safety Remote Pilot of UAS Endorsement as a foundation for developing training programs and encouraged responder input in shaping future standards. Additionally, standardized training could streamline the process for obtaining operational waivers and authorizations, such as BVLOS or operations over people.

Sub-Task 4-3 built on the previous task by focusing on airworthiness and crew training. It identified that current certification paths—standard and special airworthiness certificates—are often impractical for disaster response due to cost and operational restrictions. While sUAS are exempt from formal airworthiness certification, operators still face challenges in proving system safety for specific missions. The study suggested that a standardized set of airworthiness criteria tailored to disaster response could be beneficial.

Sub-Task 4-4 addressed UAS incursions into disaster airspace, categorizing them as either ignorant/careless or nefarious. For the former, RID under 14 CFR Part 89 helps responders identify and manage unauthorized UAS. For nefarious actors, C-UAS strategies and coordination with law enforcement are necessary. A tiered response approach was recommended to mitigate risks and locate unauthorized pilots.

Sub-Task 4-5 emphasized the need for national-level standardization of UAS practices in disaster response. It recommended leveraging existing standards from organizations like ASTM, National Fire Protection Association (NFPA), and NIST to unify procedures across federal, state, and local levels. This would ensure consistent, effective UAS deployment during emergencies.

Sub-Task 4-6 presented findings from a survey of emergency services organizations regarding UAS use. Most agencies use electric multirotor UAS and operate small fleets. However, there is variability in operational maturity and maintenance practices. The survey highlighted common challenges and provided insights into the current landscape of UAS adoption in public safety.

Sub-Task 4-7 focused on resource typing standards for UAS, which fall into two main categories: capability and performance. FEMA and the NWCG use these standards to classify UAS by their primary functions for disaster response. These standards also define minimum training, operational qualifications, and certifications for UAS operators and support personnel. As UAS technology evolves, these resource typing standards are expected to adapt accordingly.

Sub-Task 4-8 addressed challenges with the SGI process, which is used to obtain operational approvals for UAS during disaster response. The study found that the SGI process can be inconsistent, with some responders receiving approvals in real time, while others experienced significant delays. Faster approvals were more common during large-scale disasters with established TFRs. To mitigate delays, responders are encouraged to plan ahead, establish FAA contacts, create letters of agreement with partners, and define criteria for TFRs in advance.

4.4 Domestic and International Outreach

Task 6 of A62 focused on carrying out a robust outreach component aimed at expanding engagement with emergency response practitioners both domestically and internationally. Throughout the program, the research team attended or organized 39 outreach events with a wide range of stakeholders, including NASA, FEMA, National Oceanic and Atmospheric Administration (NOAA), the Department of Transportation, Department of Homeland Security (DHS), and local emergency management agencies. Activities ranged from technical demonstrations and disaster drills to academic presentations and international competitions. These engagements helped validate research in real-world settings and fostered partnerships that could support future disaster response innovations.

4.5 Data Storage and Sharing

The A62 research Task 5 focused on assessing data sharing and storage considerations for UAS operations in emergency response. A62 Task 9 developed the framework and architectural requirements for the development of a data collector tool and accompanying database.

4.5.1 Assessment of Data Sharing and Storage Requirements

4.5.1.1 Data Portal Requirements

A centralized interagency data portal for UAS-collected disaster response data would significantly enhance coordination, data sharing, and operational efficiency across agencies. Despite the increasing reliance on UAS in emergencies, responders face persistent challenges in managing and utilizing aerial data. A centralized portal would address these issues by offering a cloud-based, geospatially focused platform for uploading, reviewing, and searching UAS data. It would support various data types—photos, videos, orthomosaics, LiDAR, and flight paths—and include metadata for each upload to enhance searchability. The portal would also streamline the FAA's SGI waiver process by allowing operators to submit flight plans and credentials for rapid review. Activation protocols, access controls, and time-limited data review permissions would ensure secure and efficient use. Drawing on models like FEMA's Domestic Operations Awareness and Assessment Response Tool (DAART), this portal would fill a critical gap in disaster data infrastructure, enabling faster, safer, and more informed emergency response.

To be effective, the portal must be deployed in a secure, cloud-based environment and maintained to industry standards. It should support a wide range of UAS data formats and offer high reliability (99.9% uptime), even in low-connectivity disaster zones. The system must be searchable by disaster type, location, date, and other metadata, and should follow ISO 19115 NAP metadata standards. Usability is key, with intuitive interfaces, training resources, and GIS-independent functionality. Interactive features should allow users to overlay, compare, and annotate data layers, enhancing situational awareness. Security and privacy protections must be robust, including secondary reviews for sensitive content and strict access controls. Integration with external platforms like FEMA's GIS tools should be possible, with data sharing contingent on uploader consent and privacy review. Additionally, the portal could serve as a communication and coordination hub during disasters, enabling UAS operators, the FAA's SOSC, and state agencies to collaborate more efficiently. It would allow state agencies to submit tasking letters, host geospatial flight plans for FAA review, and provide shared coordination tools—such as standardized spreadsheets—for real-time operational planning among multiple UAS teams. This dual role as both a data repository and coordination platform would make the portal an indispensable asset in modern disaster response.

4.5.1.2 Cybersecurity Risks

The growing use of UAS in disaster and emergency response introduces a range of cybersecurity risks that must be proactively addressed. These risks span across UAS hardware, software, networks, ground control stations, and cloud systems, as identified in a comprehensive ASSURE literature review. Disaster responders must be trained to understand and mitigate these risks, especially given the sensitive nature of the data collected. Best practices include using secure devices, encrypting data, avoiding personal device use, and employing Virtual Private Networks (VPNs) during data transmission. Responders should also assess the necessity of data collection, understand who will access the data, and have protocols in place for breach response and privacy risk evaluation. These measures are essential to protect both the integrity of UAS operations and the privacy of affected communities.

Additionally, special considerations must be made for the unique conditions of disaster environments, such as limited connectivity and chaotic operational settings, which can increase vulnerability to cyber threats. UAS systems should be secured and monitored, and personnel should be vetted and trained in cybersecurity protocols. While US government guidance recommends using secure-by-design systems like those on the Blue UAS list, many disaster response organizations rely on more affordable, widely available Chinese-made platforms. Given budget constraints and operational needs, it is often impractical to exclude these systems entirely. Instead, responders should follow Cybersecurity and Infrastructure Security Agency's (CISA) cybersecurity recommendations for mitigating risks when using such platforms. Ultimately, a balanced approach is needed—one that prioritizes security while recognizing the practical realities of disaster response operations.

4.5.1.3 Requirements for Central Database of UAS Capabilities

A central database of UAS system and sensor capabilities is essential for supporting disaster and emergency response operations, especially as the UAS market rapidly evolves. This database should be built on standardized test methods and maintained by a designated agency, with input from real-world disaster response practitioners. Key requirements include regulatory compliance (e.g., RID, Part 107), comprehensiveness through regular updates, and credibility ensured by expert evaluators with technical and operational experience. The database must also prioritize relevance by focusing on UAS platforms suited for high-precision mapping and data collection, which are critical in disaster scenarios. Additionally, it should be user-friendly, featuring intuitive search tools, vendor information, expert notes, and visual references to help users make informed decisions about UAS selection and deployment.

4.5.1.4 Metrics for Use of UAS During Disaster and Emergencies

To improve the understanding and effectiveness of UAS use in disaster and emergency response, a comprehensive and standardized set of metrics should be developed and maintained in a centralized database. These metrics should cover a wide range of categories, including system-level data (e.g., UAS type, manufacturer, costs, flight hours, and maintenance), organizational information (e.g., agency type, pilot certifications, training, and prior deployments), and incident-specific details (e.g., disaster type, location, mission types, SGI waivers, and operational tempo). Additional categories should include software used for flight planning and data processing, records of accidents and technical issues, and public interactions. Data metrics should track the type, size, and handling of collected data, including whether it was reviewed or redacted for privacy risks. Aggregated data should also provide insights into the overall UAS disaster response landscape, such as the frequency of UAS deployments by region, platform usage trends, and the number of incidents responded to annually. These metrics will help inform best practices, improve safety and efficiency, and support broader adoption of UAS in emergency management, while also addressing privacy, security, and operational challenges.

4.5.1.5 Evaluating Data for Potentially Harmful Information

Concerns over the misuse of drone-collected data during disasters have grown alongside the widespread adoption of UAS technology, especially as public awareness of facial recognition and AI capabilities increases. While UAS data is invaluable for emergency response, it can also pose significant privacy and security risks, particularly when it includes personally identifiable information (PII) or demographically identifiable information (DII). The "mosaic effect," where multiple data sources are combined to reveal sensitive details furthers amplifies these risks. Despite the existence of general best practice guidelines from organizations like FEMA and CISA, there is a lack of specific, standardized procedures for evaluating, redacting, or securing UAS data before storage or sharing. Real-world incidents and legal cases highlight the legal and ethical complexities of drone surveillance. To address these challenges, the development of detailed best practices and AI-assisted tools is recommended to help analysts identify and mitigate privacy risks in large UAS datasets. These practices should be integrated with centralized data systems, such as the proposed Interagency Data Portal, to ensure responsible data handling while preserving the operational benefits of drone technology in disaster response.

4.5.2 Database Design and Architecture

The Flight Events System framework developed in A62 Task 9 is a centralized platform designed to manage and distribute data collected during UAS flight missions for emergency response. An overview of the system is presented in **Error! Reference source not found.**2. It automates the ingestion, organization, and dissemination of mission data—such as images, videos, and geospatial metadata—into a structured pipeline that feeds directly into ArcGIS Online Apps and an SQL-based Data Collector. Each emergency response is categorized as an "Event," with its own dedicated ArcGIS App that maps and displays geotagged media. The system also manages user access and permissions, ensuring data security and relevance. Additional metadata, including exchangeable image file format (EXIF) tags and user credentials, support data analysis and system integrity. PowerBI is used to generate visual reports from the collected data, enhancing situational awareness and decision-making.

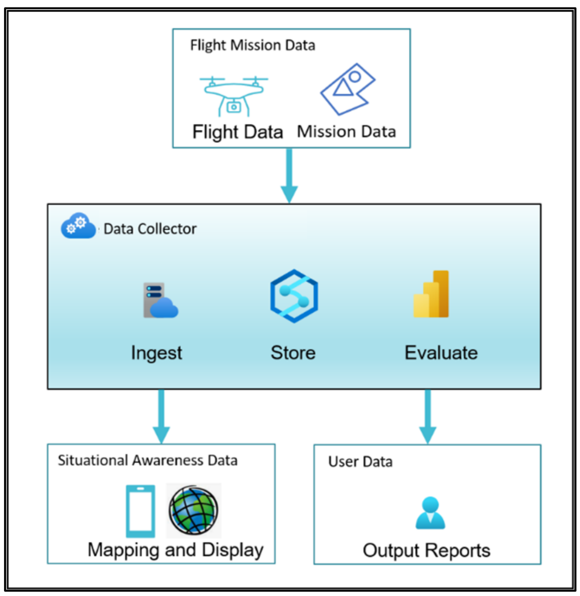

Figure 2. Flight Events System Overview

The Data Collection and Analysis Process of the Flight Events System outlines how UAS flight mission data are uploaded, processed, and managed to support emergency response operations. UAS Operators use a dedicated portal to upload mission data to approved Events, which are then automatically stored in Azure Blob Storage and processed into the system's SQL database and ArcGIS Online Apps. Public Safety Commanders manage Events through a Command Portal, where they can create, archive, and control user access. ArcGIS Users, often analysts, interpret and configure map data to support decision-making, while PowerBI Users generate reports and visualizations from the metadata. These outputs can also be shared with the FAA for regulatory or research purposes. The system enforces strict data governance and access control based on the principle of least privilege, assigning specific permissions to five user roles: System Administrators, Public Safety Commanders, ArcGIS Users, UAS Operators, and PowerBI Users. This ensures secure, efficient data sharing while maintaining operational flexibility during emergency responses.

4.6 UAS Flight Testing Events, Scenarios, and Additional Use Cases

This project included provisions for partner institutions to perform mock and real-world operations to support the full range of disasters and emergency services. The objective of A62 Task 7 was to conduct outreach with local, state, federal, and international communities involved in disaster response and recovery to embed university capabilities in relief efforts and expand the scope of ASSURE research outcomes. These events and activities, in conjunction with the sets of Additional Use Cases identified and analyzed within A62 Task 3 serve to inform technological solutions to enable expanded operations of UAS, assess the optimal UAS capabilities for various disaster types, define the proper coordination procedures amongst multi-agency collaboration, and capture valuable metrics of UAS to enhance the standardization of operational best practices as well as best practices for data collection and sharing.

4.6.1 Weather Events

4.6.1.1 Hurricane Beryl Flood Response, UVM, 2024

4.6.1.1.1 Overview

On the night of July 10 and into July 11, 2024, Hurricane Beryl hit Vermont, causing a rapid rise in water level in rivers across the state, which include the Winooski, Lamoille, and Passumpsic. Between July 11 and July 22 there were a total of 143 sUAS flights across the states that included mission for capturing oblique aerial imagery, aerial video, and mapping data such as 2D true-color orthoimagery and 3D UAS-LiDAR. The city of Barre and the town of Plainfield, which saw similar impacts during the Great Vermont Floods of 2023, were severely impacted by the high-water levels through rapid erosion in the riverbanks, small-scale landslides, road washouts, and other property damages. UVM used UAS to capture EO orthoimagery for damage assessment purposes and record keeping, as well as 3D UAS-LiDAR to capture elevation data of washouts and landslides. Planning for these missions included official requests from the Vermont SEOC. Missions in Barre and Plainfield required collaboration with town and city representatives such as the Barre City Fire Chief, the Plainfield Emergency Manager, as well as local residents in order to navigate the washed-out terrain and locate areas of interest for data capture.

Use cases for these missions included:

- Flight missions which required a multirotor UAS equipped with a true-color sensor using an automated flight plan for capturing true-color orthoimagery.
- Flight missions which required a multirotor UAS equipped with a LiDAR sensor using an automated flight plain for capturing highly detailed elevation information of road washouts and small-scale landslides.
- Flight missions that required large-scale true-color orthoimagery capture using a VTOL UAS equipped with a EO camera.

- Flight missions that required large-scale true-color orthoimagery capture using a fixed-wing UAS platform equipped with a true-color camera with OOP capabilities for data capture over residents collaborating for relief efforts and other crowded areas.
- Flight missions that included collaboration between multiple UAS teams in separate locations, which included planning discussions of how an area would be divided for optimal data capture and constant communication to allow for airspace deconfliction during flights.

4.6.1.1.2 Lessons Learned

The primary lessons learned from the Hurricane Beryl Response can be categorized into the following categories:

SGI Request Process

- The SGI request process is still evolving and can be slower than expected, especially during nationwide disasters or when SOSC staffing is limited.
- Delays in SGI processing can hinder time-sensitive missions, such as capturing high-water marks during flood response.
- Establishing best practices and standardized training for submitting SGI requests would improve efficiency for both the requesters and the SOSC.

Communication and Tasking

- Strong communication and collaboration with local agencies, first responders, and community members are essential, especially in unfamiliar areas.
- Confusion existed around where to send UAS tasking requests.
- Directing agencies to the appropriate EOC contacts helped streamline the tasking process.

Data Management and Processing

- Data tracking followed the models, using a daily-updated spreadsheet to monitor:
  - Outstanding data requests
  - Progress of data collection and processing
  - Dissemination and sharing to requestors and local/state/federal agencies
- Cloud-based processing was done using ArcGIS SiteScan, enabling:
  - Simultaneous processing of multiple orthomosaics
  - Faster turnaround times (overnight or within hours)
- Unlike the previous response where VCGI hosted the ArcGIS Online Group, UVM created and managed their own group and granted access to VCGI.
  - This allowed UVM to instantly share data to the cloud.
  - VCGI could then integrate datasets into web apps for public access and FEMA SARCOP without downloading large files.

4.6.1.2 Vermont Landslide and Flooding Response, UVM, 2024

4.6.1.2.1 Overview

In late July 2024, the Passumpsic River in Vermont's Northeast Kingdom reached moderate flood levels, causing ongoing impacts through early August of the same year. Over eight days, 40 UAS flights with EO and LiDAR sensors captured critical imagery and elevation data, documenting water levels, road washouts, landslides, and infrastructure damage from the flooding event.

4.6.1.2.2 Lessons Learned

Effective UAS response to this flooding event relied on integrating diverse sensor technologies, coordinating between teams and agencies, and applying past data management strategies to streamline workflows. Employing various UAS data collection methods and utilizing platform-specific capabilities provided invaluable adaptability as needs and conditions changed frequently. Clear communication and formalized tasking further improved operational efficiency of the UAS response.

- EO and LiDAR-equipped multirotor UAS were effective in capturing flood and landslide impacts, while fixed-wing UAS provided efficient battery life and OOP capabilities. To collect LiDAR data, lower flight altitudes were needed, and dense, mountainous terrain required significant time and effort for VLOS operations.
- Coordination and communication between UAS teams was essential for efficient mapping of St. Johnsbury and Lyndon, though formal VT EOC tasking further streamlined operations.
- Data management practices from previous flood responses in 2023 and from Hurricane Beryl provided a solid solution for tracking of data collection, processing, and dissemination.
- Time of day and environmental conditions played a role in effective data collection as well. Dusk mapping led to poor feature clarity in orthomosaics but could be improved with image editing after the data was collected.

4.6.1.3 Additional Use Cases: Drought, Flood, Heatwave, Microburst, Tornado

4.6.1.3.1 Overview

UAS equipped with various sensors were deployed to respond to weather related disasters, including monitoring drought in maize fields, assessing flood damage, mapping urban heat hotspots, and evaluating tornado and microburst impacts. Data collected from UAS flights was processed and analyzed, and effectively improved situational awareness, disaster response, and agricultural water management.

4.6.1.3.2 Lessons Learned

In these case studies, advanced UAS sensor capabilities and high-resolution UAS imagery contributed to better decision-making in drought, flood response, urban heat mitigation, and structural damage evaluation. Considerations such as air traffic and flight path planning did pose operational challenges.

- Data accuracy for environmental and disaster assessments was significantly enhanced by UAS when compared to traditional methods.
- UAS improved environmental monitoring and disaster response, enhancing drought tracking, flood assessment, heatwave mitigation, and damage evaluation after tornadoes and microbursts.
- Advanced sensor payloads, including IR, EO, LiDAR, and multispectral cameras, provided high-resolution imagery for better decision-making in agriculture and urban planning.
- Cloud-based data processing significantly improved efficiency, enabling quicker analysis, response, and mitigation.

- Strategic flight planning was found to be critical, since pre-programmed flight paths did not always work well for flood response, and considering air traffic concerns was imperative for operating UAS in post-hurricane environments.

4.6.2 Geohazard Events

4.6.2.1 Additional Use Cases: Avalanche, Dust Storm, Landslide, Lava Flow, Tsunami, Post-Earthquake Inspection

4.6.2.1.1 Overview

UAS have played a significant role in geohazard disaster response and monitoring, as showcased in these six case studies. The advanced imaging and data collection capabilities of UAS were utilized for avalanche search and rescue efforts, mapping tsunami-damaged infrastructure, collecting mid-storm atmospheric pressure measurements, landslide and lava flow risk assessment and mitigation, and to improve comprehensiveness of damage assessments.

4.6.2.1.2 Lessons Learned

UAS have proven to be invaluable tools in geohazard disaster response, monitoring, and mitigation by providing real-time data, enabling predictive modeling, and supporting emergency operations. Advancements in UAS technology such as improved sensors and machine learning integration continue to enhance the effectiveness of UAS in extreme environments and complex disaster scenarios.

- UAS enhanced avalanche disaster response by providing real-time imagery to locate and assist victims.
- Multi-sensor UAS improved hazard assessment capabilities and efficiency, as seen in landslides, lava flow monitoring, and tsunami damage mapping. Advancements in UAS technology like machine learning applications, structural mapping, and operations in GPS-denied environments enabled more comprehensive disaster assessments.
- 3D mapping can support infrastructure planning and reconstruction and improve future resiliency. Long-term UAS data collection enabled predictive modeling and helped anticipate future movement of landslides, lava, and other geohazards.
- UAS were able to navigate various extreme environments, including high-dust and low-pressure conditions, proving their viability as a response tool.
- Collaboration with local authorities promoted effective deployment, as seen in landslide assessments supported by law enforcement. UAS also contributed to improved response times, allowing for quicker evacuation and mitigation in hazardous conditions.

4.6.3 Fire Events

4.6.3.1 Additional Use Case: Wildfire

4.6.3.1.1 Overview

During the California wildfires in August 2021, multirotor and VTOL UAS were equipped with IR and EO cameras to track fire movement and heat signatures. This technology provided firefighters with essential data to assess terrain, effectively deploy resources and personnel, and determine where to establish fire-containment lines.

4.6.3.1.2 Lessons Learned

Utilizing UAS for wildfire response improved situational awareness and decision-making, leading to safer and more efficient firefighting efforts. Real-time data UAS collection and mapping enhanced resource allocation and minimized risk to response personnel.

- UAS technology improved fire monitoring and containment strategies.
- IR and EO cameras provided critical real-time insights.
- Aerial mapping enhanced resource and operational planning and deployment.
- UAS reduced exposure to hazardous conditions for firefighters and other response personnel.
- Integrating UAS into emergency response improved overall operational efficiency and safety.

4.6.4 Technological and Anthropogenic Events

4.6.4.1 Oil Spill Response, UVM, 06/12/24

4.6.4.1.1 Overview

This functional exercise focused on evaluating the application and effectiveness of UAS to respond to a mock oil spill along Lewis Creek in North Ferrisburgh, Vermont on June 12, 2024, providing a learning environment to identify gaps in policies, procedures, and interagency coordination. Primary objectives included strengthening communication and coordination among agencies, demonstrating real-time UAS capabilities for situational awareness and hazard monitoring, and producing and sharing UAS-derived imagery to support informed decision-making. Planning for the functional exercise involved a series of interagency meetings to select exercise sites, while internal meetings within the UAS Team focused on planning UAS operations to support boom deployment. The exercise required collaboration between representatives from numerous agencies including ground teams for oil boom deployment and aerial teams for UAS deployment. Multirotor and VTOL UAS were deployed for data collection by teams from UVM and the Vermont State Hazardous Materials (HAZMAT) Response Team.

The following use cases were tested during the exercise:

- A multirotor UAS equipped with an EO camera was manually piloted to provide a continuous aerial livestream by sharing the UAS controller screen via Microsoft Teams, allowing remote viewers to gain situational awareness throughout the exercise.
- A second UAS Team used a multirotor UAS equipped with a true-color camera and a retrofitted gas sensor—visually monitored through the onboard camera—to manually fly at low altitude routes to collect real-time gas readings during the exercise.
- The third UAS team conducted automated multispectral mapping with a VTOL UAS equipped with a multispectral sensor, capturing 5-band imagery over the exercise site to generate rapid orthomosaics for analysis.
- Following mapping operations, a team manually piloted a small, consumer UAS to collect oblique photos and videos of the exercise area for visual documentation and stakeholder engagement.

4.6.4.1.2 Lessons Learned

The exercise highlighted the importance of thorough coordination, communication, and planning when integrating UAS into multi-agency response efforts, particularly in constrained or public spaces where distractions, limited space, and competing priorities can affect operations. Key challenges included integrating UAS data into the broader response system, managing shared airspace and launch zones, and ensuring end-users are aware of and equipped to leverage tools like livestreaming and situational awareness feeds. Technical gaps—such as optimal gas sensor integration, mapping priorities and timing, and multispectral data requirements—also underscored the need for further research and interagency knowledge sharing.

- Looking ahead, future deployments would benefit from thorough site analysis and proactive coordination to aid in selecting viable launch zones and mitigating risk, particularly in complex or public environments. Enhancing collaboration between UAS operators and ground teams, streamlining airspace management through roles such as an "air boss," and designating separate launch and landing zones for each UAS team can significantly improve operational efficiency and safety.
- Platforms used for situational awareness should be maneuverable, capable of hovering, equipped with EO/IR sensors, and ideally able to provide livestreaming capabilities.
- While UAS-based livestreams can bridge communication gaps between aerial teams and ground crews, ensuring that intended users are aware of and can access these resources remains a challenge, warranting further research into low-cost, accessible livestreaming solutions.
- For mapping in confined areas, vertical takeoff platforms with streamlined imaging workflows have proven effective. However, continued research is needed to establish best practices for UAS use during oil spills, including identifying optimal spectral bands for detecting oil, determining the most useful timing for data collection during mitigation efforts, and defining the spatial extent required to support decision-making.
- Affordable and simple gas sensor integrations also remain a critical area for future development.
- Building pilot confidence and flight proficiency through hands-on training, credentialing, and scenario-based exercises is essential for effective emergency response.
- The establishment of clearer policies surrounding data retention and platform selection will help ensure UAS deployments are consistent, ethical, and technically robust across a variety of emergency scenarios.

4.6.4.2 Kansas State Fair, KSU, 09/06/24 – 09/15/24

4.6.4.2.1 Overview

This live event focused on using UAS to enhance situational awareness during the Kansas State Fair over ten days in September 2024. This provided an opportunity to test the integration of UAS technology and a COP in a public safety environment during an active large-scale event. Primary objectives included reducing communication barriers across agencies, enhancing decision-making through a COP, and demonstrating the ability to disseminate UAS data to a remote location. Before the event, a custom COP was developed in the TAK system to create a more robust version that was specific to UAS operations and common disaster response efforts. Three different multirotor UAS platforms equipped with EO and IR sensors were manually piloted to integrate into the COP and deliver real-time data to command personnel, such as full motion video, asset tracking, and officer locations.

4.6.4.2.2 Lessons Learned

The Kansas State Fair UAS exercise highlighted challenges in communication, software stability, and operational efficiency. Limited access to law enforcement alerts delayed response times, while TAK software instability caused misplaced data markers and video latency issues that disrupted situational awareness. Despite some persistent technical challenges, improved TAK operations and the integration of RID and Automatic Dependent Surveillance–Broadcast (ADS-B) technology enhanced airspace monitoring and overall coordination.

- UAS teams should be included in real-time alert platforms or have dedicated liaisons to ensure timely access to critical information, reducing response delays in emergency scenarios.
- Stability enhancements in TAK are necessary to prevent misplaced data markers and video latency disruptions, while standardized onboarding methods and comprehensive documentation will improve efficiency and usability.
- Camera and sensor placement consistency must be enforced to prevent operational errors, critical data transmission systems should always be backed up with battery power, and physical setups like external displays need stability improvements for challenging environmental conditions.
- Pre-event training on TAK functionality will optimize response times, utilizing RID and ADS-B technologies strengthen airspace monitoring, and future enhancements should prioritize seamless integration of advanced night-flight sensors.
- Iterative improvements in TAK software and interagency coordination are making a difference, but further refinements can enhance reliability; lessons from this deployment should inform future strategic enhancements in UAS operations during large-scale events.

4.6.4.3 Mock Airplane Emergency Response, NMSU, 11/12/24 – 11/13/24

4.6.4.3.1 Overview

This functional exercise was conducted on November 12–13, 2024, at College Ranch, New Mexico, and focused on evaluating the use of UAS in providing effective and efficient responses to different disasters and emergences, such as an aircraft crash scenario. The primary objectives were to evaluate the effectiveness of UAS platforms and various sensors in identifying crash sites, locating survivors and hazards, mapping the area before and after disturbance, and capturing lessons learned to improve disaster response operations. Planning for the event spanned over six months and included detailed documentation of aircraft, sensors, flight procedures, data management, and communications, with test formats and content refined through iterative improvements based on prior ASSURE flight test experience.

The following use cases were tested during the exercise:

- EO and IR flights were used to assess search progress, locate a simulated survivor, and identify hazards.
- Small multirotor UAS rapidly generated maps to support search and rescue efforts

- Multispectral, EO, and LiDAR sensors captured pre- and post- wreckage maps for crash investigation.

4.6.4.3.2 Lessons Learned

The Mock Airplane Crash Emergency Response Test successfully demonstrated the effectiveness of UAS in search and rescue, site mapping, and real-time monitoring. While flight missions were completed safely under Part 107 operations, some equipment challenges and post-processing limitations were noted. UAS proved valuable in survivor location and hazard assessment, but terrain and environmental conditions influenced operational efficiency.

- There are a number of platform concerns to take into consideration. Certain UAS platforms require compass calibration for consistent performance in varied locations. Additionally, UAS coordinate display methods vary by platform, impacting the ability to relay location data to first responders. Some platforms also experienced battery failures and camera shutter issues, requiring adjustments mid-operation.
- Rugged terrain, shifting winds, and colder temperatures affected flight operations and battery performance. Testing onboard UAS systems for real-time temperature and wind speed monitoring could improve operational safety in challenging terrain.
- During SAR, thermal imaging was effective for live survivor detection but less useful for locating victims in a recovery scenario once body temperatures equalized with surroundings. Future research into UAS-based communication capabilities, such as speakers or device deployment, could improve survivor interaction.
- It was recognized that mapping products require significant time to render, limiting immediate availability for response efforts. LiDAR mapping in this scenario did not provide high-quality wreckage detail, reducing its value for post-accident analysis. A tradeoff analysis between product quality, flight altitude, flight time, and post-processing needs could help define best practices.
- Clear operational protocols for guiding rescue personnel via UAS imagery improved safety and effectiveness. Further development of operational protocols for altitude, standoff distances, and optimal viewing angles could enhance future UAS effectiveness.

4.6.4.4 Additional Use Cases: Environmental Monitoring and Protection

4.6.4.4.1 Overview

These use cases highlight the utility of UAS for environmental monitoring and protection. A combination of multirotor and fixed-wing UAS, along with hyperspectral, EO, infrared, and LiDAR sensors were deployed in each scenario. Applications included tracking invasive plant species, mapping rainforest deforestation canopy changes, distinguishing pollution sources, monitoring wildlife populations, and detecting illegal hazardous waste disposal.

4.6.4.4.2 Lessons Learned

- UAS imagery provided valuable insight into the monitoring of invasive species spread, species identification, and informed control strategies.
- EO imagery effectively mapped canopy coverage and tracked changes, while also providing data on leaf phenology. LiDAR data collection could improve accuracy, especially in densely forested areas.

- Following disaster events, UAS imagery and ML provided effective classification of coastline debris as organic or manmade. High-quality data collection was essential to train reliable machine learning models for such an application.
- UAS mapping consistently provided a more effective and efficient method for wildlife tracking and animal population assessments compared to traditional ground-based methods.
- The use of UAS IR imagery for aerial surveillance was an effective tool for detecting water pollution, pollution sources, and improving regulatory compliance.

4.6.4.5 Additional Use Cases: Infrastructure and Utilities Management

4.6.4.5.1 Overview

These use cases highlight the utility of UAS as effective tools for infrastructure and utilities management. A range of platforms including multirotor, fixed-wing, and tethered systems were deployed with a variety of payloads including EO, IR, LiDAR, moisture detection sensors, and spotlights to address infrastructure and utility concerns. Applications included assessments of bridges, dams, culverts, buildings, and highways as well as monitoring of pipelines, landfills, subsidence, and wastewater facilities.

4.6.4.5.2 Lessons Learned

UAS proved to be effective tools for infrastructure and utilities management by providing rapid deployment during emergencies, enhancing situational awareness, reducing risk for personnel in particularly dangerous or hazardous areas, and improving data collection through their ability to conduct aerial assessments of hard-to-reach places, generate high-resolution 3D maps, and monitor environmental hazards. Additional lessons learned are that:

- Multirotor UAS are ideal for close-range inspections, such as culverts, bridges, and confined areas, due to their stability and maneuverability. Fixed-wing UAS are best suited for covering large areas, like pipeline and levee assessments, as they provide longer flight times and broader coverage.
- UAS can conduct fast aerial searches and structural assessments, making them ideal for an emergency situation. UAS are also capable of long-term monitoring to help identify slow-developing risks, so leveraging UAS for routine infrastructure inspections ahead of time could instead enable early detection of risks before they escalate into emergencies.
- While UAS provide valuable data, thermal resolution and imaging clarity in some UAS systems remain inadequate for detecting finer details, which can hinder accurate assessments of structural vulnerabilities or environmental hazards.
- UAS should be embedded within existing emergency response frameworks to maximize their utility and streamline coordination with public agencies. Real-time streaming of UAS data to centralized command centers ensures prompt analysis and actionable insights.
- Operators must be equipped with specialized knowledge in UAS technologies to ensure accurate assessments, effective crisis management, and optimal safety procedures. Operating UAS in urban or sensitive environments requires clear guidelines to address airspace restrictions, public safety, and liability issues.

4.6.4.6 Additional Use Cases: Disaster and Response Support

4.6.4.6.1 Overview

As shown in these use cases, UAS outfitted with advanced sensors such as EO, thermal, LiDAR, and multispectral, have been deployed across various sectors for disaster response and support. The ability of UAS technology to provide high-resolution mapping and real-time surveillance enhanced safety, decision-making, supported response and recovery efforts, and mitigated disaster impacts.

4.6.4.6.2 Lessons Learned

UAS enhanced emergency and disaster response by providing accurate, real-time data for situational awareness, resource distribution, and safety assessments. Using UAS EO, LiDAR, IR, and gas detection sensors, the technology supported debris management, search and rescue, infrastructure inspection, hazard monitoring, and medical supply delivery. Effective flight planning and technological integration were essential to maximize the utility of UAS in complex disaster scenarios, ensure informed decision-making, and effectively improve recovery efforts.

- Emergency operations were improved by utilizing UAS for debris management, mass fatality identification, and search and rescue. IR, EO, and LiDAR sensors allowed responders to create detailed maps, locate survivors, and assess risks in disaster zones.
- UAS high-resolution mapping and real-time surveillance detected structural damage, hazardous materials, oil spills, and power line issues following disasters. Autonomous drones with gas and vibration sensors enhanced early detection and response to pipeline leaks and confined space hazards.
- Fixed wing and multirotor UAS supported supply chain logistics by identifying blockages, surveying damage, and monitoring resource distribution. They enabled rapid medical delivery, mass antibiotic dispensing, and improved response times in remote and disaster-stricken areas.
- UAS equipped with cellular payloads established temporary communication networks for responders and tribal governments during emergencies, which helped maintain communication in disaster zones. UAS were also utilized to support evacuation planning by identifying safe zones and obstacles.

4.6.4.7 Additional Use Cases: Public Safety and Technology

4.6.4.7.1 Overview

These applications highlight how UAS are increasingly used for security, disaster response, and forensic investigations. UAS provided real-time mapping, surveillance, and hazard detection to support law enforcement and emergency responders. UAS technology was utilized to improve situational awareness, support efficient resource allocation, and enhance safety in high-risk environments.

4.6.4.7.2 Lessons Learned

UAS aid in security, safety, and emergency response by assisting in threat detection, disaster recovery, and environmental hazard assessment. Equipped with EO, IR, LiDAR, and gas sensors, they can provide crucial insights into crowd monitoring, crime scene documentation, radiation detection, and hazardous material assessments. UAS are a valuable tool for public safety given their ability to map affected areas, provide real-time event monitoring, and assist in forensic investigations.

- For security and law enforcement applications, UAS can assist in mapping high-risk areas, monitoring crowds, and providing real-time surveillance.
- Equipped with thermal, EO, and LiDAR sensors, UAS can assess structural damage, identify hazardous materials, track pollution, and monitor radiation levels in nuclear incidents.
- UAS can aid in documenting crime scenes, reconstructing crash sites, and supporting wreckage recovery and other investigative operations.
- Emergency communication can be greatly enhanced by using UAS to deploy temporary networks to support responders and affected communities during crises.

4.7 Conclusions

A62 built upon the previous research phases by focusing on technological solutions for expanded operations, data sharing and storage considerations, and community outreach. Key findings of A62 include:

- **Exploration of Advanced Technologies:** A62 explored technologies like UAS swarms, RID, and automated air boss systems, analyzing their potential benefits and current limitations for disaster response.
- **Development of Data Sharing Framework:** A62 highlighted the need for a centralized interagency data portal to facilitate secure and efficient data sharing and addressed critical cybersecurity and privacy concerns.
- **Extensive Community Engagement:** Outreach activities conducted in A62 fostered valuable relationships with stakeholders and facilitated the dissemination of research findings and best practices.

This research advanced understanding around the integration and effectiveness of UAS in emergency response and public safety operations. By grounding research in real-world applications and fostering community-based collaboration, the research questions addressed critical challenges related to autonomy, cybersecurity, and regulatory impacts. Research focus on data management and interagency coordination further strengthened understanding of disaster response capabilities, while outreach helped define domestic and global best practices.

To effectively implement and expand upon these research findings, continued strategic effort and investment in legislative adaptability, interagency collaboration, technological innovation is essential. Successful implementation of the research findings will rely on a robust regulatory framework that balances security, efficiency, and accessibility. Standardizing UAS operational protocols, including airworthiness guidelines, crew training, and fleet coordination, will be critical. Further policy improvements could focus on streamlining approval processes for expanded UAS operations, including BVLOS missions, while maintaining compliance with evolving national defense legislation. Strengthening stakeholder partnerships and securing funding for pilot programs and further research is essential to ensure that implementation aligns with evolving operational needs. Additionally, continued international outreach is necessary to integrate global best practices into domestic UAS disaster response strategies and standards. Future developments for advanced technologies could include refining UAS swarm capabilities, enhancing automation in air traffic management, and improving cybersecurity safeguards for real-time data sharing. An established, centralized interagency data portal would provide secure and efficient data-sharing practices, and address cybersecurity risks and privacy concerns. Effective integration of such a data portal will require strong community engagement to foster trust and awareness among public safety personnel and policymakers. This research establishes a critical foundation for advancing UAS technology, ensuring that public safety operations remain adaptable, efficient, and well-coordinated amid evolving challenges and operational demands.

5 LESSONS LEARNED

A consistent theme in the lessons learned from the three phases (A28, A52, and A62) is the critical importance of preparedness, coordination, and adaptability. Success hinges on thorough pre-mission planning, standardized checklists, and real-time communication. Teams must be trained in FEMA ICS protocols and maintain certifications (e.g., Part 107) to ensure safe and effective operations. UAS equipped with EO, LiDAR, thermal, and gas sensors significantly enhance situational awareness, hazard detection, and decision-making. Real-time data streaming and post-flight processing are essential for timely insights. Multirotor UAS are ideal for close-range inspections and confined areas, while fixed-wing platforms excel in large-area assessments. Swappable payloads and terrain-aware flight planning tools improve mission flexibility. Scalable, secure, and interoperable data systems are needed to handle the volume and variety of data collected. Time synchronization and standardized formats are essential for cross-agency collaboration. Seamless collaboration between UAS teams, EOCs, and local authorities is vital. Defined roles (e.g., UAS Air Boss), shared communication protocols, and centralized command integration improve efficiency and safety.

Across all three phases there were four common themes that were continuously reported in the lessons learned sections of the reports:

- **Training & Credentialing**: Comprehensive training in mission planning, platform operation, and emergency protocols is essential. Scenario-based exercises build pilot confidence and operational proficiency.
- **Environmental Challenges**: Operations in extreme conditions (e.g., volcanic eruptions, avalanches, oil spills) require robust platforms, backup systems (e.g., PPK/RTK), and contingency planning for weather and GPS loss.
- **Community Engagement**: Involving local stakeholders, including medical personnel and law enforcement, enhancing mission success and fostering trust. Outreach and education are key to public acceptance and effective deployment.

- **Ethical & Legal Considerations**: Privacy, data retention, and airspace safety must be addressed through clear policies and responsible practices, especially in sensitive or urban environments.

6 NEEDS AND GAPS

Across all three phases, several crucial needs, gaps, and lessons learned emerged:

- **Need for Standardized Policies and Procedures:** A consistent need across all phases was the development of nationally recognized standards and guidelines for UAS operations in disasters. This includes addressing airspace management, data security, privacy, and public perception.
- **Gap in Real-world Disaster Deployment:** While mock exercises provided valuable insights, there remains a significant gap in understanding UAS performance in actual disaster scenarios.
- **Lesson Learned - Importance of Interoperability:** Interoperability between different UAS platforms, software systems, and agencies is crucial for effective disaster response. Standardized training, data formats, and communication protocols are essential.
- **Need for Scalable Data Management Solutions:** The volume of data generated by UAS in disaster scenarios necessitates the development of scalable data management, processing, and sharing solutions.
- **Gap in Understanding Long-Term Impacts:** Limited research has been conducted on the long-term impacts of UAS integration on disaster preparedness, recovery, and community resilience.
- **Lesson Learned - Value of Multi-Agency Collaboration:** Effective disaster response requires seamless collaboration between different agencies and stakeholders. Pre-event planning, communication, and clearly defined roles are essential.

7 RECOMMENDATIONS

Based on the analysis of the previous phases, the following objectives and priorities are proposed for Phase IV (A84):

- **Develop and Test Standardized Protocols:** A84 should prioritize the development and real-world testing of standardized protocols for UAS operations in disasters, addressing airspace management, data security, privacy, and communication.
- **Evaluate UAS Performance in Real-world Disasters:** A84 should create opportunities for UAS teams to participate in real-world disaster response efforts, collecting data and evaluating performance under realistic conditions.
- **Advance Technology Solutions:** Continue research and development of promising technologies identified in A62, such as swarms, RID, and automated air boss systems, focusing on overcoming current limitations and enhancing their capabilities for disaster response.

- **Develop and Implement Scalable Data Management Solutions:** Develop and implement scalable data management solutions that address storage capacity, data security, privacy, and interoperability challenges.
- **Conduct Longitudinal Studies:** A84 should include longitudinal studies to assess the long-term impacts of UAS integration on disaster preparedness and community resilience.
- **Address Ethical and Legal Considerations:** Conduct research on the ethical and legal implications of UAS use in disaster response and develop guidelines for responsible data handling and privacy protection.

8 CONCLUSION

A28, A52, and A62 collectively advanced the integration of UAS into disaster preparedness and emergency response. A28 focused on developing detailed CONOPs by analyzing historical disasters and conducting stakeholder interviews across federal, state, and local agencies. This phase identified how UAS had been used effectively in past events and outlined potential roles, aircraft types, sensor payloads, and regulatory needs for future disaster scenarios. Building on this foundation, A52 tested these CONOPs through 29 real-world exercises and simulations across the US, including hurricanes, wildfires, pandemics, and floods. A52 emphasized the importance of reducing response times, improving interagency coordination, and delivering real-time data. It also highlighted the need for standardized UAS operations, regulatory flexibility, and consistent training across agencies. A52 concluded with recommendations for Phase III, including refining emergency-specific guidelines, enhancing data collection standards, and fostering industry partnerships. A62 extended the research by exploring advanced technologies such as UAS swarms, RID, and automated air traffic coordination. It emphasized the creation of a centralized, secure interagency data portal to support real-time data sharing while addressing cybersecurity and privacy concerns. A62 also prioritized community engagement to build trust and disseminate best practices. The project underscored the need for continued investment in regulatory adaptability, technological innovation, and stakeholder collaboration to ensure UAS can be safely and effectively deployed in evolving disaster response environments. These phases provide a comprehensive roadmap for integrating UAS into national and global emergency response frameworks, emphasizing preparedness, interoperability, and innovation.

Key gaps identified in the three previous phases (A28, A52, and A62) include a critical need for standardized national policies and procedures to guide UAS operations in disaster scenarios, particularly concerning airspace management, data security, privacy, and public trust. A major gap remains in the deployment of UAS in real-world disasters, as most insights to date are based on simulations rather than actual emergencies. The importance of interoperability—across platforms, software, and agencies—has emerged as a key lesson, highlighting the need for standardized training, data formats, and communication protocols. Additionally, the lack of scalable data management systems limits the ability to process and share the vast amounts of data generated during UAS missions. There is also insufficient understanding of the long-term impacts of UAS integration on disaster preparedness and community resilience. Finally, the value of multi-agency collaboration has been reinforced, emphasizing the need for coordinated planning, communication, and clearly defined roles before disaster events occur.

It is recommended that Phase IV, A84, should focus on enhancing UAS disaster response by developing and testing standardized operational protocols, particularly in areas like airspace coordination, data security, and communication. It should facilitate real-world disaster deployments to evaluate UAS performance under authentic conditions. Continued advancement of technologies such as UAS swarms, RID, and automated air traffic systems is essential to overcome current limitations. Scalable and secure data management solutions must be implemented to ensure interoperability and privacy. Longitudinal studies should be conducted to assess the sustained impact of UAS on disaster preparedness and community resilience. Finally, ethical and legal considerations must be addressed through research and the creation of responsible data handling guidelines.

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