First Responder UAS Use in Post-Disaster Environments

Michael C. Hunter*
Iowa State University

Cuong (Patrick) Quach and Kyle Smalling
NASA Langley Research Center

Uncrewed Aircraft Systems (UASs or drones) are increasingly used by public safety agencies for a variety of missions, including for disaster relief. These post-disaster missions involve a set of threats that are distinct from the threats confronted by UAS on average flights. To help discover and analyze these threats we conducted a series of interviews with members of public safety agencies and asked them about their current UAS use. This paper contains a summary of the information we gathered in these interviews, as well as a discussion of some of the threats to UAS missions in post-disaster environments.

I. Introduction

Uncrewed Aircraft Systems (UASs) are an increasing part of the national airspace of many countries in recent years. These UASs (commonly refered to as drones) are used by hobbyists, for commercial and industrial applications, and by public safety workers such as police, fire departments, and other emergency responders. There is a lot of recent work focusing on UAS use during disaster relief, both theoretical and applied. The regulatory environment surrounding UAS use is changing in the United States, and various groups are currently working on the next generation of UAS capabilities and traffic management systems.

NASA created the System Wide Safety (SWS) project in 2018 with the intention of creating new technical solutions to allow safe, rapid, and repeatable access to the national airspace for emerging aircraft technologies [1]. One of the Technical Challenges associated with SWS is a Safety Demonstrator series where new technologies for UAS flights are tested against a realistic disaster relief scenario, such as a fire, flood, or hurricane [1]. As part of this technical challenge, we wanted to discover how UASs are currently being used by public safety agencies in general and in post-disaster scenarios specifically.

In the summer of 2024 the authors interviewed individuals from several agencies currently flying UASs for public safety and disaster relief, in order to gather information about realistic missions, hazards, and concerns from those in the field. We then used the information gained in those interviews as well as prior information about post-disaster environments to create a hazard list for post-hurricane public safety UAS flights. We present the information about the interviews and the hazards in this paper.

II. Motivation

The System Wide Safety group at NASA is working toward creating technologies to assist with future UAS flights in post-hurricane environments [1]. It is therefore important to understand current UAS use in post-hurricane environments. However, UAS use is currently in a state of flux.

Regulations surrounding UAS usage have been rapidly changing. As recently as 2013, a drone company providing assistance to flooded areas in Colorado was informed that such flights were illegal and was told to stop* [2]. However, more recent disasters have encouraged UAS operations [3]. It was not until 2016 that the FAA released Part 107, a set of regulations and certification for private UAS pilots to operate in the national airspace [4]. The FAA allowed private UAS pilots to participate in the Low Altitude Authorization and Notification Capability (LAANC) in 2019, which is an approval process to allow drone flights to fly in controlled airspace [5]. The FAA is currently working on finalizing their vision for UAS Traffic Management or UTM, which will be a communications and authorization platform for UAS pilots flying in controlled airspaces [6].

At the same time as the FAA is decreasing some restrictions on flights in the national airspace, some restrictions on the types of drones that can be flown are increasing. The Florida legislature banned state agencies from using

*Email: mchunter@iastate.edu

*Reports initially were that FEMA stopped these flights, but FEMA denied this. It is not clear where the stop order originated.

Chinese-made drones in 2023 [7]. Federal agencies were banned from using drones manufactured in China in early 2024 [8, 9]. A total ban on all DJI drones was passed by the US House of Representatives (but not the Senate) in 2024 [10]. Current guidance from the US government is to avoid all use of DJI drones in the US [11]. All of this change means that research into UAS use requires recent information in order to be accurate. This paper aims to be a step in that direction.

III. Related Work

Since this work focuses on threats to UAS flights during disaster relief operations, we review some of the literature about UAS hazard analysis as well as UAS disaster relief missions.

Hazards in UAS flights. Washington et al. conduct a literature review on risk models of ground impact for UAS flights [12]. Stevenson et al. present an analysis of both perceived and actual UAS flight risk, as well as mitigation strategies [13]. Lum and Tsukada utilize mathematical models to estimate both ground impact and mid-air impact risk from UAS flights. [14]. Go et al. use the System-Theoretic Process Analysis to perform a hazard analysis of UAS use as a tool for public safety in developing countries [15].

Denney and Pai [16, 17], Denney et al. [18], and Clothier et al. [19] have published papers describing in general terms the construction of safety cases for UAS flights, including hazard analysis and risk assessment. Gradyon et al. describe how to scope the hazard analysis process to specific aircraft types and missions [20].

UAS use in disaster relief. Glantz et al. provide an overview of UAS missions from a variety of disaster management environments [21]. Nikhil et al. provide a breakdown of UAS components, as well as a framework for classifying UAS disaster relief missions [22]. Maza et al. experiment with multiple UASs working together to achieve disaster relief goals [23]. Research by Ray et al. has investigated emergency calls that involved UAS in a single geographic region, finding primary use cases of searches, evidence collection, SWAT, wildland firefighting, and structure firefighting [24]. Hell et al. classify types of disaster as well as types of UAS that could be flown in disaster relief missions for those disasters [25].

Many researchers have presented case studies about the use of uncrewed robotic vehicles in a variety of disaster relief applications such as earthquakes, floods, and forest fires [3, 26–30]. Mohd Doud et al. provide a scoping review of papers focusing on UAS disaster management uses and missions showing that interest in these missions is increasing, worldwide, and encompasses a wide variety of types of missions [31].

IV. Methodology

This paper discusses the results of several interviews with first-responder organizations that fly UASs. We then use those results to generate a list of hazards or threats associated with UAS flights in a post-hurricane environment.

Interview process: During the summer of 2024, we contacted the emergency management agencies in most of the states on the Atlantic and Caribbean coasts via email to ask if they were using UAS in disaster management or if they knew of other agencies that were. We initially received responses from four of these agencies (out of more than 20 inquiries) who either agreed to interviews or to forward our requests onto other agencies. We used these contacts to get in touch with several other organizations we had not originally contacted that are currently using UASs for public safety. The overall list of agencies we contacted can be seen in Table 1.

We found that many state and local emergency management agencies do not directly operate drones. Instead, some states have UAS programs through their state troopers or highway patrol. Other states said they had no state-level UAS programs, but some county or city agencies had such programs.

In the end, we arranged for interviews with five agencies that currently use UAS in emergency management applications or who advise those who do. Two of those groups brought two people to the interview, so we interviewed a total of seven people. Each interview lasted about an hour and was largely free-form, with the authors asking questions and following up as seemed appropriate. Specific topics of discussion included the number UASs flown, number and training of personnel, types of missions flown, and hazards that the UASs typically encounter. (See Section V.A for more detail.)

We interviewed one national organization focused on providing assistance to UAS public safety personnel; the other four organizations were public safety agencies of varying size. One was a county-level agency that had only a few pilots and three drones. Another was a state-level agency with 30 pilots (increasing to 50 by the end of the 2024) each with their own drone. The third was a state-level agency with 320 pilots (increasing to 370 by the end of the 2024) and 360 aircraft. The last was a city fire department in a large urban area with 16 full time and 50-80 part time pilots and more than 20 aircraft. This information, along with agency identifiers, can be found in Table 2.

Location	Agency
National	AIRT and DRONERESPONDERS
Maine	ME Emergency Management Agency
New Hampshire	NH Homeland Security and Emergency Management
Massachusetts	MA Emergency Management Agency
Rhode Island	RI Emergency Management Agency
Connecticut	CT Division of Emergency Management and Homeland Security
New York (state)	NY Division of Homeland Security and Emergency Services
New York (city)	Fire Department of New York City
New Jersey	NJ State Police (Emergency Management Section)
Pennsylvania	PA Emergency Management Agency
Delaware	DE Emergency Management Agency
Maryland	MD Department of Emergency Management
Washington DC	DC Homeland Security and Emergency Management Agency
Virginia	VA Department of Emergency Management
	VA State Police
North Carolina	NC Department of Public Safety
South Carolina	SC Emergency Management Division
Georgia	GA Emergency Management and Homeland Security Agency
Florida	FL Division of Emergency Management
Alabama	AL Emergency Management Agency
Mississippi	MS Emergency Management Agency
Louisiana	LA Governor's Office of Homeland Security and Emergency Preparedness
Texas	TX Division of Emergency Management
	TX Department of Public Safety
Puerto Rico	Puerto Rico Emergency Management
US Virgin Islands	VI Territorial Emergency Management Agency

Table 1 Contacted agencies

These interviews were recorded and automatically transcribed, and the authors took separate notes on the conversations. These notes were then compared for similar themes and topics by the first author, which were then used for determining the current UAS usage.

Identifying current UAS missions: We used our interviews to create a list of UAS missions currently flown by the agencies we interviewed. We compared this list to existing literature to ensure we had not missed obvious types of missions. This list includes both non-disaster as well as post-disaster missions.

UAS hazards: We used our mission list and current literature on UAS hazard analysis to create a non-exhaustive list of hazards that UAS operators face during non-disaster and post-disaster missions.

V. Results

In this section we summarise the results of the interviews discussed in Section IV.

A. Interview Findings

While we did not follow a script of questions during our interviews, we asked many similar questions to all of agencies, while still allowing other topics to arise naturally. Examples of our questions include:

- What emergency management and disaster relief missions do you currently use UASs for?

Agency	Description	Pilots
A	Rural county Emergency Management Agency	2
B	National drone organization	0
C	State Patrol Department	30-50
D	State Patrol Department	320-370
E	City Fire Department	50-80

Table 2 Details of interviewed organizations

- What safety hazards concern you most with your current UAS missions? What safety hazards concern you most with disaster relief UAS missions?
- How do you handle getting airspace authorizations to fly your UAS? What kinds of waivers do you have for those missions?
- Do you fly your missions under visual line of sight (VLOS) or beyond visual line of sight (BVLOS) rules? How do your pilots know and manage the requirements for each type of flight?
- What kinds of UAS systems are you currently flying?
- Who flies your UAS? What kinds of training do they have to fly them? What kinds of ongoing training do they require?
- What kinds of sensors do you have or need on your UAS for the missions you fly?
- What kinds of technologies do you think you will require in the future for UAS missions to be safe and effective?

The missions that the interviewees said they were flying are described in section V.B, and discussion of the threats associated with these flights are described in sections V.C and V.F. Here we limit our discussion to items outside those areas.

Pilot skill and training. The interviewees all stressed that the most important element in operating UASs safely is the skill and experience of the pilot. We spent a fair amount of the interview time with each agency discussing how their pilots were trained. All of the agencies with pilots (A, C, D, E - see Table 2) require their pilots to get their Part 107 Remote Pilot Certificate from the FAA prior to any in-house flight training. However, all the agencies also agreed that Part 107 certification by itself was insufficient to ensure their pilots were highly skilled, especially since Part 107 does not require any actual flight time [4]. All of the public safety organizations we spoke to had implemented their own training standards although those standards vary from agency to agency. Agency D utilized the NIST[†] "Standard Test Methods for Small Unmanned Aircraft Systems" [32] as a basis for their training. The NIST training involves careful, controlled flights around a set of targets, as seen in Figure 1. Agency C specified that they intentionally did *not* use the NIST training for their pilots, arguing that while the precision flying required by the NIST standards is a valuable skill to have, most law enforcement UAS missions do not involve precision flying. Most law enforcement missions, Agency C argued, involve flying the UAS up to altitude and keeping watch over an area, or using autonomous mapping functions. Agencies A, C, D, and E each created some or all of their own training procedures and requirements which they said they were happy to share with other agencies who needed help. Agencies C and D specified that they train out-of-state pilots in their training programs.

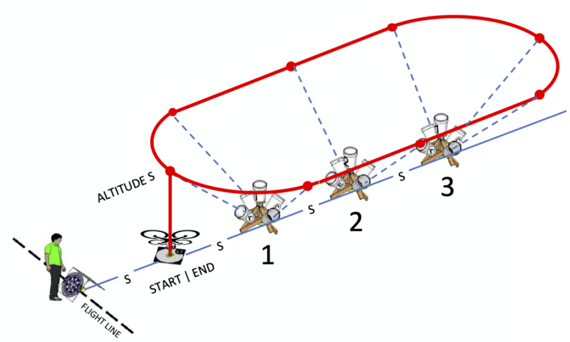


Fig. 1 One of the NIST piloting tests with associated apparatus (buckets) [32].

Agency A mentioned that the NFPA[‡] has published NFPA 2400: "Standard for Small Unmanned Aircraft Systems (sUAS) Used for Public Safety Operations" [33]. These standards are fairly comprehensive, covering the organizational deployment of sUAS, professional qualifications for sUAS personnel, and maintenance of sUAS. However, these standards do not describe teaching or assessment methods. Indeed, NFPA 2400: 5.1.3.2.2 states "The public safety entity shall establish instructional priority and training program content to prepare personnel to meet the [job performance

[†]National Institute of Standards and Technology
[‡]National Fire Protection Association

requirements] of this standard." As an example of the kind of requirement that NFPA 2400 provides, in section 5.3.2 entitled "Flight," it specifies that when taking off, the pilot shall:

> Perform take-off under the regulatory requirements as determined by the [authority having jurisdiction] given a specific sUAS and confirmed state of readiness, so that the sUAS takes off after having complete system checks and flight is initiated and maintained in a manner compliant with regulatory requirements.

In other words, the pilot should take off consistent with the rules of wherever they are taking off, which is true, but not perhaps very useful when using the NFPA 2400 to write your own training curriculum.

Similar to the standards published by the NFPA, ASTM[§] has published F3379-30, "A Standard Guide for Training of Public Safety Remote Pilot of Unmanned Aircraft Systems (UAS) Endorsement" [34]. Most of the standards in ASTM F3379-20 reference other standards for which the pilots should meet the requirements. This includes referencing the NIST flight training mentioned above. So there are several sources for standards for pilot training that the agencies can reference for their own training programs, although many of them reference each other and all relevant laws and regulations, which makes using them as a reference difficult.

All of the agencies that have developed their own training programs incorporate required flight time into their programs.

Knowledge of laws and regulations. A key aspect of the training the pilots receive is knowledge of the relevant flight regulations and laws that apply to UAS flights. The pilots must learn the visibility requirements, altitude limits, and separation distance from clouds, buildings, and people, for each type of flying that they might do. For instance, many public safety UAS flights *can* operate under Part 107 restrictions (visual line of sight, staying well clear of clouds, and staying no more than 400 feet above ground level) [4]. However, all the agencies we talked to have received waivers for some of those requirements in some circumstances and in some locations, or more generally for public safety flights over their entire region. Therefore, the pilots need to know the specific flight rules required by those waivers.

Types of pilots. The agencies we spoke to said that most of their pilots are not full-time, and they became pilots in addition to other jobs they have. For instance, highway patrol officers or firefighters may become the designated UAS operator for their unit, while continuing their previous work. If they do work full time as a pilot, it is likely they work a specific type of job (such as flying missions along the US southern border), or they fly missions over a very large area (such as an entire county or state), or, perhaps, both.

UAS Maintenance. Each of the agencies we spoke to have different ways of handling maintenance of their UAS fleet. Agency D, with a very large drone fleet, has in-house technicians who can repair most or all of the drones, or who know who to contact to do so. These individuals handle annual inspections, or inspections of damaged UASs. In smaller agencies such as A, C, and E, most of the monthly or semi annual inspections of the drones are performed by the pilots themselves. In all the agencies, pilots perform standard inspections of each UAS before each flight. In these smaller agencies annual inspections and drone repair is handled by an outside contractor.

Notices to Air Missions. Agency D noted that every flight made by one of their public safety officers includes a Notice to Air Mission (NOTAM) [35] as well as an email sent to local airports, informing all air traffic in the area that a UAS flight will be taking place at a certain time, operating within a certain volume of airspace. These notices are automatically sent out by the software that this agency uses to manage their UAS fleet, called DroneSense. DroneSense is a platform made for public safety and emergency management agencies to keep track of their equipment, stream video from any drone to any location, and map out the location of their drones [36]. DroneSense is used by Agencies D and E, while Agency A uses DroneLink[¶] [37]. Sending out a NOTAM for every flight could be tedious without an automated system to assist with that process. As this point came up late in our interviews we were unable to ask the other agencies about whether they send NOTAMs for all of their flights.

Efforts to ban Chinese drones. One repeated point of discussion was the current political movement in the US to ban drones from certain countries, especially China, from being imported into or used within the United States. These bans were first mentioned by Agency C. These bans are mostly focused on the Chinese company DJI, which controls over 70% of the world drone market [38], but the proposed bans would likely affect Autel and other Chinese drone manufacturers. In Florida, public safety agencies were forbidden in 2023 from using drones manufactured in a list of "countries of concern," which includes China. This law caused many public safety agencies in Florida to have to ground their entire drone fleets. The law initially provided no money to help those agencies purchase new UASs [7]. Federal agencies were banned in late 2023 from purchasing or using DJI drones [8].

[§]ASTM used to stand for American Society for Testing and Materials, but now the organization's name is simply ASTM International.

[¶]We did not ask specifically what software plaftorm Agency C uses.

At the US federal level, the "Countering CCP Drones Act," first introduced in 2022, would add all DJI drones to the FCC's Covered List [10]. Being placed on the Covered List would indicate the FCC believes DJI drones pose an "unacceptable risk" to the security of the United States, and would ban the sale of such drones in the US [39, 40]. This bill passed the US House but not the Senate and has not been signed into law. However, the 2025 National Defense Authorization Act (which was passed into law) contains language that would effectively ban all drones made by DJI and Autel and any associated companies if those drones fail a security review, or *if one is not performed* within 1 year (Public Law 118–159 §1709.a) [41]. Current guidance from the US Cybersecurity and Infrastructure Security Agency (CISA) is "to procure UAS that follow secure-by-design principles, including those manufactured by U.S. companies" [11]. A review of security research into DJI drones by Shelly concludes that "DJI UAS have a demonstrated history of cyber vulnerabilities, which is unsurprising for any software-based products developed for the consumer market" [42].

Despite these possible security vulnerabilities, all of the agencies we interviewed agreed that DJI drones were much cheaper and more capable than other brands of drones, which is why they have such a large market share. If DJI drones are banned throughout the US, then many public safety agencies will need to replace most or all of their drones fleets, at a large cost. This possibility is, understandably, a concern to these agencies. Agencies A, D, and E all fly DJI drones either exclusively or as a major part of their fleets.

Drone use to enforce laws. Agencies C and D stressed that their UAS fleets are *not* used for direct law enforcement. For instance, the agencies do not use their UASs to detect speeding cars and to write tickets. These agencies want their UAS fleets to be seen generally as helpful and useful, and not feared by the general population. UASs are used as aerial video for some arrests or SWAT raids in these locations, so there may already be some negative feelings toward these drones from some populations. However, the individuals we interviewed stated they wished to avoid having their drones "make bad law." There are a number of privacy concerns related to UAS use by law enforcement [43], and these agencies claim that they do not want a court decision to limit what they are able to use UASs for. Agency D stated that UASs could not be used to gather probable cause against a person, but that they could be used to observe police operations or gather evidence of crimes in public areas or after warrants were issued.

The information we gathered in our interviews helped to shape our understanding of how UAS pilots are trained, what regulations they must follow, and how information about these flights is communicated. However, the largest portion of the time in our interviews was dedicated to the current uses of UASs by public safety officers, which is the topic of Section V.B.

B. Current UAS Uses in Public Safety

Missions: According to our interviewees, the majority of public safety or disaster management UAS missions are for the purpose of aerial video. This video is streamed from the UAS to the pilot, as well as other pubic safety personnel who might benefit from it, some of whom might be located many miles away. Applications such as DroneSense can stream the video from any connected drones to anyone as required by the mission [36]. There are a large number of instances where such video is helpful. Some examples that were mentioned in our interviews:

- Detailed mapping:
  - For navigation
  - For detecting changes or damage
  - For planning future operations
  - For keeping track of the progress of fire or flooding
  - For automotive crash reconstruction
  - For crime scene reconstruction
  - For research purposes, such as environmental assessments
- Streaming or downloaded video:
  - For intelligence, surveillance and reconnaissance (ISR) at crime scenes
  - For ISR for warrant service
  - For ISR during large public events and protests
  - For search and rescue
  - For searching for wanted suspects
  - For border patrol
  - For ISR inside of buildings
- Inspections of infrastructure such as powerlines, bridges, above-ground pipes, etc.
- Inspections of crops (post-disaster for public safety organizations)

Drone	Dims. ($l \times w \times h$ (mm))	Wt. (kg)
Quadcopters		
Skydio X2	$660 \times 560 \times 200$	1.3
Skydio X10	$790 \times 650 \times 145$	2.2
DJI Mavic Mini	$245 \times 289 \times 55$	0.25
DJI Mavic 2 Enterprise Dual	$322 \times 242 \times 84$	1.0
DJI Matrice 200 V2	$883 \times 886 \times 398$	5.0
DJI Matrice 30T	$470 \times 585 \times 215$	3.8
PDW C-100	$1625 \times 1651 \times 279$	9.7
VTOL Aircraft		
Autel Dragonfish (std)	$1290 \times 2300 \times 460$	7.5

Table 3 Drones in the fleets of the interviewed agencies. Dimensions and weights taken from drone manufacturer specifications. [44, 47–49]

- Information about traffic conditions
- Coordination of highway patrol during evacuations

Since video streaming is such a key part of the missions listed above, it is vital that UASs used in emergency management have high-quality video cameras and other sensors, as well as the ability to stream video to an internet-connected ground station, or directly to cellular or satellite internet services. Many modern drones have several video cameras that come standard, with the possibility of purchasing and carrying upgraded camera packs [44] (at M350 product page). In addition to visual-light or RGB cameras, UASs can carry infrared or thermographic cameras to detect differences in heat [45], multispectral cameras to enhance the camera's ability to detect hidden objects [46], and LiDAR‖ to provide extremely detailed 3-D models of an environment [44] (at Zenmuse product page). The type of sensor a UAS needs is driven by the missions that it will fly, but at the same time those missions are constrained by the sensors available in a given UAS fleet. For this reason, the agencies we talked to purchase a variety of different types of UASs for the various types of missions they fly.

UAS types: The UAS types used by the interviewees are listed in Table 3. This table is not exhaustive of the drones that these organizations are currently flying, only of the drones that they mentioned in the interviews. The drones listed in Table 3 are mostly quadcopters, ranging from small handheld models (Mavic Mini) to military models (PDW C-100). The one VTOL aircraft model, the Autel Dragonfish, was only used by Agency D, and is mostly used for border surveillance flights.

UASs are selected for missions in disaster relief or emergency management not only for their sensor package, but for a variety of other specifications as well. According to our interviews, these specifications include, but are not limited to:

- Battery type, battery weight, total available charge, and lifespan of the battery
- Maximum allowable windspeed, temperature range, and takeoff altitude of the UAS
- Max UAS speed, climb, and descent rates, and max roll, pitch, and yaw rates, especially if the UAS will be flown into enclosed places
- Connection frequencies and maximum connection range, encryption types, and cellular connections
- Obstacle avoidance system (to prevent collisions with structures and other obstacles)
- Detect and avoid system (to prevent collisions or near-misses with other aircraft)
- Carrying capacity, if the UAS will be used for delivery purposes

Drone delivery: Drone delivery is an increasing area of interest for the agencies we interviewed. The primary advantage of UASs for delivering small items is that the UASs can often get to a location faster, with less expense, and with less danger to public safety officers than other assets such as helicopters, boats, or search parties. Some examples of such delivery missions mentioned in our interviews are:

- Delivering life jackets to people stranded or struggling in the water
- Delivering water or medical supplies to lost hikers
- Delivering small items such as batteries to emergency responders in the field

‖Laser detection and ranging

Another current or near-future application of UASs that Agency C is experimenting with is for the exploration of dangerous areas such as chemical spills and high-radiation areas. The use of land-based robotic systems is well documented for such missions, or for bomb disposal [50]. Properly constructed UAS could also be used in similar missions to get video of areas where it is too dangerous to send humans. The occasional loss of a drone due to chemical or radiation exposure could be well worth the risk. UASs used in such environments might need to be built or retrofitted with hardening against radiation, or sealed against chemical ingress.

Drone as a first responder: Agencies B and C discussed the concept of Drone as a First Responder (DFR). In this concept, a drone is dispatched as soon as a 911 call comes in, flying automatically to the area of the call. The drone might be equipped with emergency lights and a siren, two-way communications with a loudspeaker, and a camera, so that the emergency responders could get eyes on the scene quickly, and could start communicating with people on the ground if appropriate [51]. Of course, these drones would generally need to be flown beyond visual line of sight for such missions, and some agencies have already applied for BVLOS waivers for these flights. Use of drones in this way does raise a number of privacy and civil liberties concerns, which will only increase as drone use increases [43].

FAA regulations: All of the agencies we spoke to are required to follow FAA rules for UAS use in the national airspace. As mentioned above, hobbyist pilots are licensed under part 107 of FAA regulations, a rule that went into effect in 2016. Government agencies are allowed to obtain a Certificate of Authorization (COA) from the FAA to operate outside of Part 107 constraints. These constraints include the following [4]:

- UAS must be within visual line of sight (VLOS)
- Flight must be during the day
- UAS must remain within 400 feet of the ground or structure
- UAS has a maximum speed of 100 mph
- UAS cannot operate over people
- UAS cannot operate outside of Class G airspace (so not near airports or other controlled airspace)
- UAS and cargo must weigh less than 55 lbs (22 kg)

When operating under a COA, some of these rules can be broken if the agency can show that such flights can be conducted safely. For instance, the pilot might be able to operate the UAS beyond visual line of sight (BVLOS). All of the agencies stated that most of their flights operate under part 107 rules, but that they had received COAs for some types of operations within their states, such as flying large drones for a long distance along the US southern border. These COAs involve lengthy forms that must be filled out and the response time from the FAA can be substantial.

Overall, the primary use of UASs for these public safety agencies is intelligence, surveillance, and reconnaissance. For most of the the missions described above, the UAS does not need to fly close to people, and it can usually be routed so that it does not overfly people or buildings, decreasing the effect of ground impact should something go very wrong during the flight. However, as drones become more common, cheaper, and capable, it is likely that some missions will be flown very close to and above people, perhaps beyond visual line of sight, possibly at night or in inclement conditions. Such missions present substantial threats to people and buildings.

C. General UAS Hazards

The field of hazard analysis is broad and intricate [52] and we do not attempt to perform a full hazard analysis here. We are interested in discussing some general dangers associated with UAS flights by public safety organizations. However, even this brief discussion should be grounded in the correct terminology. Aviation hazard analyses are typically defined in terms of hazards, failures, errors, and failure conditions, as defined in ARP4654B and ARP4761A [53, 54].

Hazard: A condition resulting from failures, external events, errors, or combinations thereof where safety is affected.

Failure: An occurrence which affects the operation of an aircraft, system, equipment, item, or piece-part such that it can no longer function as intended, (this includes both loss of function and malfunction).

Error: An omitted or incorrect action by a manufacturer, crew member, or maintenance person, or a mistake in requirements, design, or implementation.

Failure condition: A condition having an effect on the aircraft and/or its occupants, either direct or consequential, which is caused or contributed to by one or more failures or errors, considering flight phase and relevant adverse operational or environmental conditions, or external event.

In this paper we describe the *causes* of failures to be events that can lead to the hazard, and the *effects* of failures to be the outcome that can result from the failure occurring. A cause of a low battery failure might be that the battery is too old to maintain its charge, with the effect that the flight will end too early. The worst-case consequences for failures during UAS flight usually involves impact with the ground, structures, or other aircraft. In each case the possibility exists for these loss events to lead to injury or death of a human, or the destruction or damage to some property. Almost all hazards we discuss could lead to one of these loss events [12]. Note that unlike with crewed aviation, the loss of a UAS will not necessarily cause any death or injury.

In Table 4 we include a list of generic failures, causes, and effects that might happen in any UAS flight. In Section V.F we discuss hurricane-specific hazards.

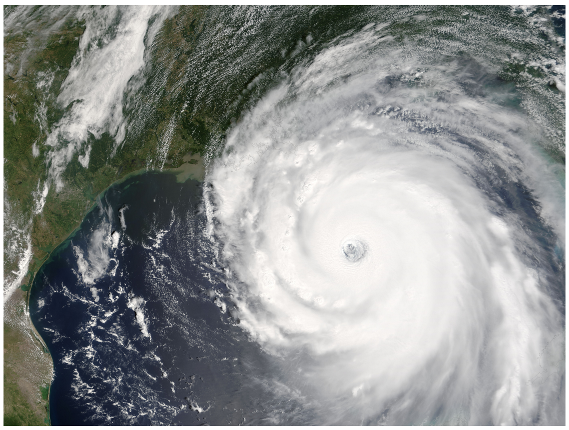
Failure or Error	Possible Causes	Possible Failure Effects
Battery Disconnection	Battery vibrates loose	LOS from Ground
Battery Low Charge	Battery failure due to age/cycles Insufficient charge for given flight Battery outside temperature limits	Early flight termination
Camera blocked	Fog/smoke/smog blocks camera	Deviation from flight plan
Control system failure	Malfunction of control system	Deviation from flight plan
Communication failure	RFI interference	Deviation from flight plan
Electronics system failure	Malfunction of electronics Water penetration of electronics RFI interference	Deviation from flight plan
Ground control sys. failure	Malfunction of GCS	Deviation from flight plan
GPS connection issue	Blockage of GPS signals Lack of sufficient GPS satellites	Deviation from flight plan
Insufficient thrust	Steady wind Wind gusts Wind shear Wind around terrain/structures Precipitation outside specs	Deviation from flight plan LOS from ground LOS from air traffic Early flight termination
Navigation system failure	Malfunction of nav system Bad sensor or sensor input	Deviation from flight plan
Navigation failure	Fog/smoke/smog prevents navigation	Deviation from flight plan
Motor failure	Exceeding design thresholds Malfunction of motors Water penetration of motor	Early flight termination LOS from ground
Rotor failure	Damage to rotors over time	LOS from ground
Detect and Avoid failure	Radar uncertainty	LOS from air traffic
Software configuration error	Software configured incorrectly Previous incorrect configuration	Deviation from flight plan
Structural failure	Structural damage from age/usage	LOS from ground
Programming error	Software violates safety limits	Deviation from flight plan
User Error	Autopilot not started correctly	Deviation from flight plan

Table 4 A sample of hazards, causes, and effects for a generic UAS flight. Note that LOS stands for "Loss of separation" and GCS for "Ground control system".

D. UAS Use in Post-Disaster Environments

The agencies that we spoke to had all engaged in post-disaster missions. These disasters might be small and local, or large and regional. They mentioned disasters such as floods, house fires, wildfires, earthquakes, tornadoes, and hurricanes. Each type of mission flown after such disasters involves different hazards to the UAS mission. Here we focus on UAS flights in a post-hurricane environment, a scenario with many parallels to other post-disaster UAS flights.

To ground this discussion in the real world, we will use Hurricane Katrina as a starting point. Hurricane Katrina was a 2005 storm that made landfall near New Orleans as a Category 3 hurricane with wind speeds over 200 km/hr, and caused massive devastation and loss of life in Louisiana, Mississippi, Alabama, and Florida [55]. A small sample of this damage can be seen in the images in Figure 2**



(a) Satellite image before landfall

(b) Flooding Damage

(c) Structural damage to buildings

(d) Emergency workers after Katrina

Fig. 2 Images of Hurricane Katrina. (All images are from Wikimedia Commons and are free to use under Creative Commons.)

The use of UASs has increased greatly in the years since Katrina's landfall. We present a fictional but similar hurricane scenario to indicate how UASs might be used in 2024. Hurricane Omega forms off the coast and develops into a Category 4 or 5 storm. Forecasts, aided by UAS meteorology flights, predict Omega's imminent landfall, causing millions to attempt to evacuate from costal cities and towns. This exodus creates enormous traffic problems on streets and highways well before the hurricane arrives, which public safety organizations need to try and alleviate, using UASs for real-time updates of the location of traffic jams and the mapping of alternate routes. Because of accurate forecasts, local, state, and national emergency response groups begin their planning, organization, and response efforts well before Omega's devastation begins. These groups move resources and personnel near to the areas of anticipated destruction, while attempting to keep those resources from being damaged or stranded. During this time UAS flights help create accurate pre-hurricane maps and images for later comparison and navigation.

**Images all from `commons.wikimedia.org/wiki/Category:Hurricane_Katrina` (accessed on 2024/07/23).

Omega makes landfall near a major city and coastline as a Category 3 or 4 hurricane, flooding low-lying areas due to rain and storm surge, destroying or damaging buildings and infrastructure, and disrupting utilities for much of the city. Following the initial landfall, emergency crews begin assessing damage, searching for trapped or injured people, and inspecting infrastructure. UAS flights are used for all of these purposes. This work continues even as the hurricane leaves the area, so the initial work is performed in poor and unpredictable weather conditions.

People who were unable to evacuate the area need to be rescued from houses and roofs, in neighborhoods with impassible roads and substantial debris and rubble. Structures are unstable and prone to collapse or shifting while people are sheltering within or on top of them, or while rescuers are searching through them. UAS missions help find these people and provide information on damaged structures to rescuers. However, navigation for both flights and ground crews is difficult due to damaged or missing landmarks, flooding, and the destruction of buildings, roads, and bridges. Rescuers search using boats in many parts of the city. UAS flights map out the new damaged areas of the city, providing real-time updates and video for rescuers. However, electricity and fuel for disaster relief workers is scarce. Communications is difficult due to radio frequency interference (RFI) from the storm and from the large number of radios in use by relief workers.

A number of non-cooperative UASs begin flying in the disaster area, piloted by news media and civilians seeking photographs or video for posterity, social media, or their own damage assessment or rescue efforts. There are a large variety of UASs flying in the area with many different capabilities. Some of these pilots do not know to coordinate with public safety officials, or decide not to do so. Even if these private pilots do coordinate their flights with public safety officials, there is no guarantee that they will follow the rules they have agreed to.

Some people on the ground try to attract the attention of UASs by throwing something at the drone, not just waving or making signs. Other people interfere with drone flights because they don't trust the public safety officers or other reasons.

Due to the extensive flooding and damage to infrastructure, there are limited take off and landing areas for UASs, especially those requiring a runway. Staging areas for disaster responders are in some cases far from the areas they are working in, and the airspace around those areas becomes extremely congested.

This short Hurricane Omega scenario presents a number of possible missions and hazards for UAS flights. These are discussed in more detail in the next sections.

E. Post-Disaster UAS missions

The disaster relief personnel responding to Hurricane Omega use their UASs for many different types of missions described above. No doubt new mission types will continue to be developed as UASs are used more often. Based on our interviews and research, we can expect UAS missions to include any or all of the following:

- **Traffic management:** Prior to landfall UASs can help manage and oversee traffic along evacuation routes. During the response phase UASs can oversee traffic involving emergency crews, avoiding damaged or flooded roads or bridges. During the recovery phase UASs can help manage the traffic of those returning to their homes.
- **General area mapping:** UAS missions can quickly generate accurate maps of damaged areas, which can help with planning, identifying areas of need, and assist with navigation for future air and ground-based missions.
- **Reconnaissance for mission planning:** UAS flights can provide intelligence, surveillance, and reconnaissance (ISR) that can be streamed back to command centers or to workers in the field, providing real-time visuals of the work being done in the disaster area. This information can make planning future missions much more efficient and effective.
- **Search and rescue:** UASs can help with search and rescue (SAR) missions. UASs equipped with infrared and multi-spectral imaging systems can help locate people by body heat, and can cover a lot of ground quickly. Small drones launched by the SAR crews can help them make detailed searches in a small area more quickly than they could on foot.
- **ISR for other teams:** UASs can be sent in advance of helicopter or land based teams on a variety of missions, to stream video to those teams and provide intelligence on what to expect in an area before they arrive. Helicopter and land based teams are usually in high demand, and using UAS video to increase the efficiency of these groups can help save many lives.
- **Damage inspections:** UASs can inspect infrastructure such as buildings, roads, houses, electrical lines, radio towers, and the like. These inspections can be done much more quickly and safely than if human crews needed to inspect each structure up close. These inspections can then help repair crews know which locations can be easily fixed, and which locations will be dangerous to work in and would be best avoided in the short term.

Inspections inside buildings: Some small UASs are designed with protection on their rotors [44] (such as the DJI Avata) allowing them to fly within buildings to help with SAR and infrastructure inspections. This might make a search of an unstable structure possible.

Drone delivery: As mentioned in Section V.B, some drone missions may also involve delivery of small items as well. Flotation devices or first aid kits could be especially helpful in the aftermath of Hurricane Omega.

F. Post-Disaster Hazards

Based on the Hurricane Omega scenario and missions presented in Sections V.D and V.E and on the interviews from Section V.A, we have constructed a list of hazards that would be relevant to our post-hurricane scenario. Most of these hazards are a direct result of the conditions present in the post-Hurricane Omega environment.

High winds: There may be high and unpredictable winds, especially immediately following the hurricane's departure. These could be exacerbated by the damage to structures and presence of debris, especially for flights very close to the ground. See the wide area of storm clouds shown in Figure 2a.

Precipitation: Similarly, there may be unpredictable and substantial precipitation in the area, especially from the tail end of the hurricane. This precipitation could make all operations in the area dangerous, but especially flights of small UASs.

Unreliable navigation aids: A UAS may find it difficult to accurately navigate due to the destruction of familiar landmarks and the general change in the appearance of the area. Some parts of the area may have lower GPS coverage than normal if there is sufficient RF interference. Navigating by map reference will be difficult. See the flooding damage in Figure 2b.

Debris or structures in close proximity to UAS flight path: UASs may be damaged during missions by impact with debris or structures. This could be especially problematic if the mission requires flight close to unstable structures which could collapse or shed debris on the UAS. There is the remote possibility that some people on the ground may throw objects at the UAS to try and get its attention. See the collapsing building in Figure 2c.

Unexpected power demands: UASs may experience unexpected power demands due to strenuous demands placed on the batteries from long missions, repeated flights in a short period of time, or the need to stay in the air longer than anticipated during missions.

Lack of available charging: The lack of electrical infrastructure means that it may be difficult to locate places to charge batteries for UASs. Many UAS operators can charge their batteries with the alternator on their car, but if there is also a lack of available fuel in the area, there may not be enough gas to supply both the battery needs of a UAS and the fuel needs of the car. See the emergency workers in a boat in Figure 2d.

Non-cooperative flights: There may be a large number of non-cooperative flights in the area from citizens or the news media, which increases the chance of a loss of separation from the aircraft, and possibly the inability to complete missions in certain areas.

Lack of good landing sites: The flooding and damage to buildings and structures could make it difficult to find places to land.

UAS flights in a post-hurricane environment are likely to share hazards with most other types of UAS flights, while experiencing some unusual or unique hazards. Some of these hazards, such as the presence of debris, extensive flooding, and collapsing houses are not typically encountered by UAS pilots and require specialized training and planning to mitigate.

VI. Discussion

In this section we discuss a few points that arise from both the interviews and the discussion of hazards from above.

Importance of pilots: Performing a full hazard analysis of the conditions found in post-hurricane environments takes a long time. A hazard analysis should be an ongoing document updated as further information comes in and as additional hazards are discovered [52, 56]. This hazard analysis provides insight for the operators for how to respond in the event of a hazard during flight. Before any flight, a pilot goes through a short checklist of items [57], but not an exhaustive listing of everything that could possibly go wrong - that information is hopefully covered by their training and experience flying. When the flight environment changes or when new hazards arise during a flight, the pilot must use their training, experience, and knowledge of the hazard analysis to make intelligent decisions in that moment. After the flight, any new experience and hazards can be integrated into the formal hazard analysis to mitigate future encounters with those hazards.

In the end, we rely on the skill of the pilot or operator to safely operate UASs. Through operations planning, preflight checklists, and in-flight monitoring, the pilots and operators are the main mitigation against risk. The pilots of the public safety agencies we spoke to engage in continual training to maintain their proficiency. Currently, much of the information about training, hazards, and mitigations are being shared informally between individuals and agencies over email, social media, and in person. This kind of local information sharing is even more important in disaster relief missions, as the number of operators who engage in these kinds of missions is small, and each new disaster may involve very different agencies and personnel. However, it is important that we attempt to capture this information to create a record of what has been tried for future pilots and researchers.

Drone delivery: Drone delivery missions are a growing source of interest for the shipping industry, medical fields, and public safety personnel [58, 59]. Since the entire point of a drone delivery mission is to get close to a person or the ground and release a payload of some sort, the risk of injury to a person is much higher than if the mission involves just taking video. As mentioned above, one of the agencies we interviewed is currently using drones to deliver emergency flotation devices and a few other emergency supplies. These delivery missions are mostly happening over the ocean, where the risk to non-involved people is reduced. Delivery missions will only grow more popular as such agencies experience success, and as drones become more capable.

Urban Air Mobility: Urban air mobility (UAM) is the concept of air vehicles flying people or cargo within a city at lower altitudes than traditional air traffic [60]. UAM can involve autonomous or -non autonomous vehicles, such as helicopters, vertical-takeoff-and-landing aircraft, and UASs, operating within urban airspace. There is an increased risk of accidents as UAM services become more common [61]. The increase in flights in congested and low-altitude airspace will make the separation of this traffic more difficult, especially if some of the traffic does not have the ability to detect and avoid other traffic. UASs operated by public safety agencies will need to carefully consider the risks of flying drones in the urban airspace of the near future. UAM traffic could also be a danger in post-disaster areas as people try to return to normal life even as disaster relief continues.

Future Planning and Regulation: Currently many agencies operate their UAS flights under COA waivers from the FAA, with training that they themselves have created, flying missions as they see fit. In the (paraphrased) words of one of our interviewees, they are making up a lot of this as they go. Drone agencies are sharing knowledge with each other directly and with organizations like DRONERESPONDERS without the guidance of federal regulators [62]. There is currently no nationally required pilot certification for these public safety pilots outside of part 107, a certification standard which does not require any flight time to receive [4]. As discussed above, several levels of government in the United States have either banned or suggested banning DJI drones [7, 10]. In Florida, this was done without consultation with local agencies [7]. DJI drones are the leading supplier of drones to hobbyists as well as safety agencies [38]. Overall, more coordination between local agencies, state and federal regulators, and state and federal lawmakers seems necessary.

VII. Threats to Validity

There are several threats to the validity of this paper.

- We only interviewed 5 agencies, with a total of 7 people interviewed. The interviewees are experienced with UAS use for public safety and emergency management. Some of those we interviewed worked on disaster relief recently before our interviews, but there are many other agencies using UASs in different ways and we did not capture a cross section of the views of the entire community.
- We chose who to interview based on who responded to us, and based off of referrals from earlier interviewees, meaning our sample is not at all random.
- None of the authors of this paper are public safety officers. While we did interview several public safety officers, there are no doubt many questions that we didn't think to ask, or facets of UAS flying for public safety that seem obvious to the interviewees that we do not understand.

VIII. Conclusion

In this paper we interviewed several public safety agencies who currently use UAS for various missions, including during disaster relief. We described how UASs are currently being used by these agencies, the types of UASs being used, pilot training considerations, and other related information. We listed representative missions likely to be flown in a post-hurricane scenario. We also researched specific dangers that would be faced by a UAS in that environment.

Acknowledgements

The research described in this proposal is funded by NASA Grant Number: 80NSSC23M0058.

References

[1] Fox, K., "System Wide Safety Project Description," , 2024. URL www.nasa.gov/directorates/armd/aosp/sws/about-system-wide-safety/.

[2] Ackerman, E., "Drone Provides Colorado Flooding Assistance Until FEMA Freaks Out," *IEEE Spectrum*, 2013.

[3] Surmann, H., Slomma, D., Grobelny, S., and Grafe, R., "Deployment of Aerial Robots after a major fire of an industrial hall with hazardous substances, a report," *2021 IEEE International Symposium on Safety, Security, and Rescue Robotics (SSRR)*, IEEE, 2021, pp. 40–47.

[4] FAA, "Part 107 Small Unmanned Aircraft Systems," 14 CFR 1F 107, 2016. URL www.ecfr.gov/current/title-14/chapter-I/subchapter-F/part-107.

[5] FAA, "UAS Data Exchange (LAANC)," , 2024. URL www.faa.gov/uas/getting_started/laanc.

[6] FAA, "Unmanned Aircraft System Traffic Management (UTM)," , 2024. URL www.faa.gov/uas/advanced_operations/traffic_management.

[7] Mower, L., "How Florida lawmakers are grappling with DeSantis' Chinese drone ban," *Tampa Bay Times*, 2023. URL www.tampabay.com/news/florida-politics/2023/05/02/desantis-drones-police-chinese-dji-american-security.

[8] Daleo, J., "Defense Policy Bill Would Ban Chinese, Russian Drone Tech in U.S." *Flying Magazine*, 2024. URL www.flyingmag.com/defense-policy-bill-would-ban-chinese-russian-drone-tech-in-u-s/.

[9] Plaza, J., "The Potential Impact of the 2024 National Defense Authorization Act on the Commercial UAV Industry," *Commercial UAV News*, 2024.

[10] Howe, S., "News Round-Up: Where things stand with the potential ban on DJI drones," *Commercial UAV News*, 2024. URL www.commercialuavnews.com/news-round-up-where-things-stand-with-the-potential-ban-on-dji-drones.

[11] CISA, 2024. URL www.cisa.gov/sites/default/files/2024-01/Cybersecurity%20Guidance%20Chinese-Manufactured%20UAS.pdf.

[12] Washington, A., Clothier, R. A., and Silva, J., "A review of unmanned aircraft system ground risk models," *Progress in Aerospace Sciences*, Vol. 95, 2017, pp. 24–44. https://doi.org/10.1016/j.paerosci.2017.10.001.

[13] Stevenson, J. D., O'Young, S., and Rolland, L., "Estimated levels of safety for small unmanned aerial vehicles and risk mitigation strategies," *Journal of Unmanned Vehicle Systems*, Vol. 3, No. 4, 2015, pp. 205–221. https://doi.org/10.1139/juvs-2014-0016.

[14] Lum, C. W., and Tsukada, D. A., "UAS reliability and risk analysis," *Encyclopedia of Aerospace Engineering*, 2010, pp. 1–12.

[15] Go, E., Jeon, H.-C., Lee, J.-S., and Lim, J.-Y., "Enhancing Urban Public Safety through UAS Integration: A Comprehensive Hazard Analysis with the STAMP/STPA Framework," *Applied Sciences*, Vol. 14, No. 11, 2024. https://doi.org/10.3390/app14114609.

[16] Denney, E., and Pai, G., "Architecting a Safety Case for UAS Flight Operations," *34th International System Safety Conference (ISSC)*, 2016. https://doi.org/10.1007/978-3-319-66266-4_11.

[17] Denney, E., and Pai, G., "Tool support for assurance case development," *Automated Software Engineering*, Vol. 25, 2018, pp. 435–499. https://doi.org/10.1007/s10515-017-0230-5.

[18] Denney, E., Pai, G., and Whiteside, I., "The Role of Safety Architectures in Aviation Safety Cases," *Reliability Engineering & System Safety*, 2019. https://doi.org/10.1016/j.ress.2019.106502.

[19] Clothier, R., Denney, E., and Pai, G. J., "Making a Risk Informed Safety Case for Small Unmanned Aircraft System Operations," *17th AIAA Aviation Technology, Integration, and Operations Conference*, 2017. https://doi.org/10.2514/6.2017-3275.

[20] Graydon, M., Neogi, N., and McCormick, F., "Scoping, Tailoring, and Abstraction Refinement in Hazard Assessment Processes," *Vertical Flight Society's 80th Annual Forum*, 2024.

[21] Glantz, E. J., Ritter, F. E., Gilbreath, D., Stager, S. J., Anton, A., and Emani, R., "UAV Use in Disaster Management." *ISCRAM*, 2020, pp. 914–921.

[22] Nikhil, N., Shreyas, S., Vyshnavi, G., and Yadav, S., "Unmanned aerial vehicles (UAV) in disaster management applications," *2020 Third International Conference on Smart Systems and Inventive Technology (ICSSIT)*, IEEE, 2020, pp. 140–148.

[23] Maza, I., Caballero, R., Capitán, J., de Dios, J. M., and Ollero, A., "Experimental Results in Multi-UAV Coordination for Disaster Management and Civil Security Applications," *Journal of Intelligent Robotic Systems*, 2011, pp. 563–585. https://doi.org/10.1007/s10846-010-9497-5.

[24] Ray, H. M., Singer, R., and Ahmed, N., "A Review of the Operational Use of UAS in Public Safety Emergency Incidents," *2022 International Conference on Unmanned Aircraft Systems (ICUAS)*, 2022, pp. 922–931. https://doi.org/10.1109/ICUAS54217.2022.9836061.

[25] Hell, P. M., and Varga, P. J., "Classification of Drones in Disaster Management," *2024 IEEE 7th International Conference and Workshop Óbuda on Electrical and Power Engineering (CANDO-EPE)*, 2024, pp. 301–306. https://doi.org/10.1109/CANDO-EPE65072.2024.10772960.

[26] Mascarello, L. N., and Quagliotti, F., "Challenges and Safety Aspects of a Disaster Relief Exercise," *Journal of Intelligent & Robotic Systems*, Vol. 88, 2017, pp. 737–749. https://doi.org/10.1007/s10846-017-0518-5.

[27] Murphy, R. R., Duncan, B. A., Collins, T., Kendrick, J., Lohman, P., Palmer, T., and Sanborn, F., "Use of a Small Unmanned Aerial System for the SR-530 Mudslide Incident Near Oso, Washington," *Journal of field Robotics*, Vol. 33, No. 4, 2016, pp. 476–488.

[28] Kruijff, G.-J. M., Pirri, F., Gianni, M., Papadakis, P., Pizzoli, M., Sinha, A., Tretyakov, V., Linder, T., Pianese, E., Corrao, S., et al., "Rescue robots at earthquake-hit Mirandola, Italy: A field report," *2012 IEEE international symposium on safety, security, and rescue robotics (SSRR)*, IEEE, 2012, pp. 1–8.

[29] Karma, S., Zorba, E., Pallis, G., Statheropoulos, G., Balta, I., Mikedi, K., Vamvakari, J., Pappa, A., Chalaris, M., Xanthopoulos, G., et al., "Use of unmanned vehicles in search and rescue operations in forest fires: Advantages and limitations observed in a field trial," *International journal of disaster risk reduction*, Vol. 13, 2015, pp. 307–312.

[30] Goodrich, M. A., Morse, B. S., Engh, C., Cooper, J. L., and Adams, J. A., "Towards using unmanned aerial vehicles (UAVs) in wilderness search and rescue: Lessons from field trials," *Interaction Studies*, Vol. 10, No. 3, 2009, pp. 453–478.

[31] Mohd Daud, S. M. S., Mohd Yusof, M. Y. P., Heo, C. C., Khoo, L. S., Chainchel Singh, M. K., Mahmood, M. S., and Nawawi, H., "Applications of drone in disaster management: A scoping review," *Science & Justice*, Vol. 62, No. 1, 2022, pp. 30–42. https://doi.org/10.1016/j.scijus.2021.11.002.

[32] NIST, "Standard Test Methods for Small Unmanned Aircraft Systems," NIST, 2019. URL www.nist.gov/system/files/documents/2019/08/21/nist-astm-nfpa_standard_test_methods_for_suas_-_maneuvering_and_payload_functionality_overiew_v2019-08-20v2.pdf.

[33] NFPA, *Standard for Small Unmanned Aircraft System (sUAS) Used for Public Safety Operations*, 2019. URL www.nfpa.org/codes-and-standards/nfpa-2400-standard-development/2400.

[34] ASTM, *Standard Guide for Training for Public Safety Remote Pilot of Unmanned Aircraft Systems (UAS) Endorsement*, 2020. URL www.astm.org/f3379-20.html.

[35] FAA, "What is a NOTAM?" , 2021. URL www.faa.gov/about/initiatives/notam/what_is_a_notam.

[36] Dronesense, "The Most Comprehensive Drone Management and Collaboration Platform on the Market," , 2024. URL www.dronesense.com.

[37] DroneLink, "Drone Flight Control," , 2024. URL www.dronelink.com.

[38] Drone Industry Insights, *The Chinese Drone Market Report 2019-2024*, Drone Industry Insights, 2024. URL droneii.com/product/chinese-drone-market-report.

[39] FCC, "List of Equipment and Services Covered By Section 2 of The Secure Networks Act," , 2025. URL www.fcc.gov/supplychain/coveredlist.

[40] FCC, "Prohibition on Authorization of "Covered" Equipment," , 2025. URL www.fcc.gov/laboratory-division/equipment-authorization-approval-guide/equipment-authorization-system.

[41] United States Congress, "Servicemember Quality of Life Improvement and National Defense Authorization Act for Fiscal Year 2025," PUBLIC LAW 118–159, 2025. URL www.congress.gov/118/plaws/publ159/PLAW-118publ159.pdf.

[42] Shelley, A. V., "Addressing Security Concerns with Chinese Drones and DJI Products," *Aviation Safety Management Systems Ltd*, 2020.

[43] Stanley, J., "Eye-in-the-sky policing needs strict limits," , 7 2023. URL www.aclu.org/documents/eye-in-the-sky-policing-needs-strict-limits.

[44] DJI, "DJI Online Store," , 2024. URL www.DJI.com.

[45] Hoshino, W., Seo, J., and Yamazaki, Y., "A study for detecting disaster victims using multi-copter drone with a thermographic camera and image object recognition by SSD," *2021 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM)*, 2021, pp. 162–167. https://doi.org/10.1109/AIM46487.2021.9517524.

[46] Shrestha, R., and Hardeberg, J. Y., "Evaluation and comparison of multispectral imaging systems," *Color and Imaging Conference*, Vol. 22, No. 1, 2014, pp. 107–107. https://doi.org/10.2352/CIC.2014.22.1.art00018.

[47] Skydio, "Skydio Online Store," , 2024. URL www.skydio.com/home-dfr.

[48] PDW, "PDW Website," , 2024. URL www.pdw.ai.

[49] AUTEL, "AUTEL Robotics Online Store," , 2024. URL shop.autelrobotics.com.

[50] Nguyen, H., and Bott, J., "Robotics for Law Enforcement: Beyond Explosive Ordnance Disposal," Tech. rep., National Institute of Justice's Office of Science and Technology, 2000. URL www.ojp.gov/pdffiles1/Digitization/190348NCJRS.pdf.

[51] Parham, W., "10 Tips for Starting a Drone as First Responder Program," , 3 2023. URL www.policemag.com/patrol/blog/15352673/10-tips-for-starting-a-drone-as-first-responder-program.

[52] Leveson, N. G., and Thomas, J. P., *STPA Handbook*, Leveson and Thomas, 2018.

[53] SAE International, "ARP4761A: Guidelines for Conducting the Safety Assessment Process on Civil Aircraft, Systems, and Equipment," , 2020. URL www.sae.org/standards/content/arp4761a/.

[54] SAE International, "ARP4754B: Guidelines for Development of Civil Aircraft and Systems," , 2023. URL www.sae.org/standards/content/arp4761a/.

[55] US House of Representatives, "A FAILURE OF INITIATIVE: Final Report of the Select Bipartisan Committee to Investigate the Preparation for and Response to Hurricane Katrina," , 2006. URL www.govinfo.gov/content/pkg/CRPT-109hrpt377/pdf/CRPT-109hrpt377.pdf.

[56] FAA, *Safety Management System Manual*, 12 2022. URL www.faa.gov/air_traffic/publications/media/ATO-SMS-Manual.pdf.

[57] Cromwell, C., Giampaolo, J., Hupy, J., Miller, Z., and Chandrasekaran, A., "A Systematic Review of Best Practices for UAS Data Collection in Forestry-Related Applications," *Forests*, Vol. 12, No. 7, 2021. https://doi.org/10.3390/f12070957.

[58] Moshref-Javadi, M., Hemmati, A., and Winkenbach, M., "A comparative analysis of synchronized truck-and-drone delivery models," *Computers & Industrial Engineering*, Vol. 162, 2021, p. 107648. https://doi.org/10.1016/j.cie.2021.107648.

[59] Scott, J. E., and Scott, C. H., "Drone Delivery Models for Medical Emergencies," *Delivering Superior Health and Wellness Management with IoT and Analytics*, edited by N. Wickramasinghe and F. Bodendorf, Springer International Publishing, Cham, 2020, pp. 69–85. https://doi.org/10.1007/978-3-030-17347-0_3.

[60] Pak, H., Asmer, L., Kokus, P., Schuchardt, B. I., End, A., Meller, F., Schweiger, K., Torens, C., Barzantny, C., Becker, D., Ernst, J. M., Jäger, F., Laudien, T., Naeem, N., Papenfuß, A., Pertz, J., Prakasha, P. S., Ratei, P., Reimer, F., Sieb, P., Zhu, C., Abdellaoui, R., Becker, R., Bertram, O., Devta, A., Gerz, T., Jaksche, R., König, A., Lenz, H., Metz, I. C., Naser, F., Schalk, L., Schier-Morgenthal, S., Stolz, M., Swaid, M., Volkert, A., and Wendt, K., "Can Urban Air Mobility become reality? Opportunities and challenges of UAM as innovative mode of transport and DLR contribution to ongoing research," *CEAS Aeronautical Journal*, 2024. https://doi.org/10.1007/s13272-024-00733-x.

[61] Graydon, M. S., Neogi, N. A., and Wasson, K. S., "Guidance for Designing Safety into Urban Air Mobility: Hazard Analysis Techniques," *AIAA Scitech 2020 Forum*, 2020.

[62] DRONERESPONDERS, "DRONERESPONDERS Public Safety Program," , 2024. URL www.droneresponders.org.