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Tech Brief

USE OF SMALL UNMANNED AERIAL SYSTEMS FOR EMERGENCY MANAGEMENT OF FLOODING

INTRODUCTION

Flooding is a unique event or occurrence: it may be a standalone incident, or it may accompany another event. As examples, a hurricane may produce flooding as well as wind damage, or a landslide may dam a river and create a flood. Flooding events are unique in terms of their scale of occurrence or time.

There is likely some warning prior to a flooding event, and flooding is generally a long duration event, when it can be weeks or months before flood dangers subside. The event may be a series of floods, with a flood from initial intense rain directly falling in the affected area, followed by river flooding from drainage or upstream rain moving into the area, as seen with Hurricane Harvey in the metropolitan Houston, Texas, area.

Flooding impacts can be gradual or sudden, such as the levee breach in New Orleans, Louisiana, with Hurricane Katrina in 2005.

Flooding poses immediate threats to personal safety and infrastructure, along with general risks of hazardous material leaks or spills. Flooding may as also result in search and recovery of missing persons.

A wide variety of unmanned aerial systems (UAS) have been used for flood events since at least 2005. UAS have been used by formal response agencies for at least 12 disasters from flooding or for events that had flooding associated with them. Following is a partial list, in chronological order, of UAS use in response to flooding, which notes how each response was able to utilize UAS differently to meet the specific needs of the event.

- Hurricane Katrina 2005. This was the first reported use of UAS. Both rotorcraft and fixed wing assets were used to determine the flood crest of the Pearl River in Louisiana and Mississippi and the risk to surrounding communities (Murphy 2014).
- Hurricane Wilma 2005. A rotorcraft UAS was used to examine the infrastructure including a bridge to Fort Myers Beach off the southwest Florida coast (Murphy 2014).
- Thailand Floods 2011. Fixed-wing UAS were used for general surveys of the flooding (Srivaree-Ratana 2012).

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Figure 1. Small UAS used by Fort Bend, Texas, Office of Emergency Management before, during, and after Hurricane Harvey flooding

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- Oso, Washington Mudslides 2014. UAS were used to provide photogrammetric mapping of the mudslide, which was used to determine where to cut an emergency bypass flood channel (Murphy et al. 2015).
- Balkans flooding in Serbia 2014. UAS was used to survey the extent of the disaster and to actively investigate why drainage mitigations were not working (Cubber et al. 2014). The UAS found a pump set up by a farmer that would have been impossible to see from the ground.
- Blanco River, Texas, flood 2015. UAS were used by volunteers in Texas to conduct searches for missing persons swept away the flood into inaccessible areas (Murphy 2016).
- Louisiana Flood 2016. UAS were used by the Tangipahoa and Washington Parish Offices of Emergency Management to determine the extent of flood, impact on transportation infrastructure, and citizens at risk (Murphy 2016).
- Texas Memorial Day Flood 2016. UAS were used by the Fort Bend, Texas, Office of Emergency Management to monitor rising flood waters and predict flooding inundation (Murphy et al. 2016).
- Hurricane Harvey 2017. UAS were used extensively by the Fort Bend, Texas, Office of Emergency Management to support all emergency support functions with 112 flights before, during, and after the flood crest (Fernandes et al. 2018).
- Hurricane Florence 2018. The North Carolina Department of Transportation (NCDOT) used UAS to assess the extent of flooding on major roadways.
- Hurricane Michael 2018. UAS flights for general damage assessment captured unreported damage to a Florida bridge. UAS with thermal imagery was also used to search for missing persons presumed swept inland with debris.

Figure 1 shows most of the UAS used by the Fort Bend County Office of Emergency Management before, during, and after Hurricane Harvey. As shown in Figure 1, these UAS are small and portable.

The most commonly used platform, which was flown in 72 of the 112 missions at Hurricane Katrina and used extensively by NCDOT for Hurricane Florence, costs less than $1K, can be folded to fit in a jacket pocket, and can be recharged from a car inverter. This indicates that agencies can now afford to adopt small UAS.

This document is organized as follows. After covering Federal Aviation Administration (FAA) regulations, it presents the seven basic missions that can be performed by small UAS, and then describes which missions are useful for before, during, and after a disaster. After review of UAS responses to flooding events, this document summarizes the primary use cases.

FAA REGULATIONS

UAS operators in both the public and private sectors must adhere to statutory and regulatory requirements. Public aircraft operations (including UAS operations) are governed under the statutory requirements for public aircraft established in 49 USC § 40102 and § 40125. Additionally, both public and civil UAS operators may operate under the regulations promulgated by the FAA.

The provisions of 14 CFR Part 107 apply to most operations of UAS weighing less than 55 lbs. Operators of UAS weighing greater than 55 lbs may request exemptions to the airworthiness requirements of 14 CFR Part 91 pursuant to 49 USC § 44807.

UAS operators should also be aware of the requirements of the airspace in which they wish to fly. The FAA provides extensive resources and information to help guide UAS operators in determining which laws, rules, and regulations apply to a particular UAS operation. For more information, please see https://www.faa.gov/uas/.

THE SEVEN BASIC SMALL UAS MISSIONS

Following Fernandes et al. 2018, UAS missions can be divided into seven basic categories, as described below. UAS have been used for all seven categories for flooding events, although not all seven for a single event. Missions provide either images and video, digital elevation maps, or photogrammetric stitching of images into an orthomosaic image (see Figures 2 through 4).

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Figure 2. Video and imagery

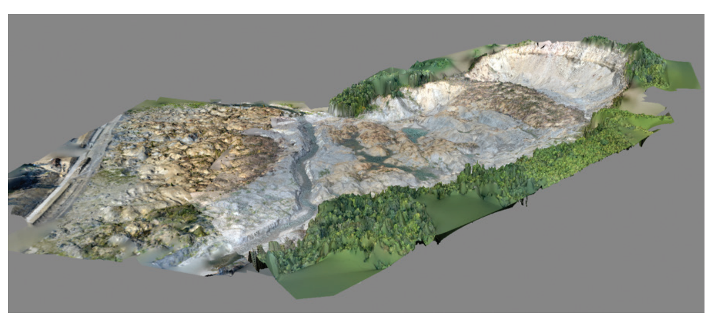

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Figure 3. 3D digital elevation map

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Figure 4. Orthomosaic image

Note that photogrammetric stitching and elevation mapping require images to be gathered in sequences and viewpoints that are not amenable to real-time human comprehension.

Strategic Situation Awareness, Survey, and Reconnaissance

Strategic situation awareness (SA), survey, and reconnaissance consists of multi-purpose scans of the area. Depending on the specifics of the mission, the flights may be either real-time video and imagery or photogrammetric mapping. Typically, situation awareness favors a cinematic style of flying to give the viewer the sense of the area, while surveys and reconnaissance favor specific paths (e.g., lawnmower scans, follow a river).

Figure 5 shows a lawnmower scan path for a UAS to follow to gather images for a photogrammetric map of a neighborhood affected by Hurricane Harvey.

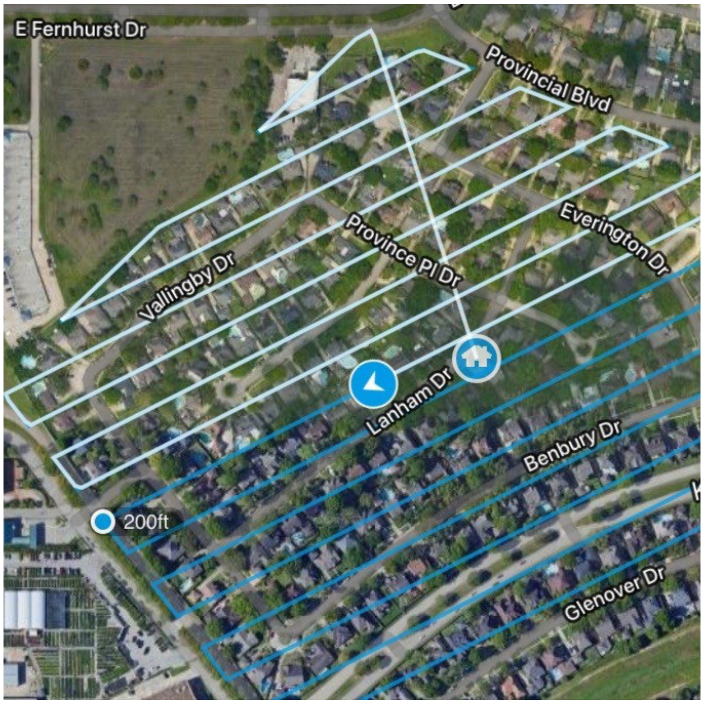
For floods, the objectives of this category of mission are to answer questions such as where's the flooding? How bad? Are people in distress? What is the state of the transportation infrastructure, roads and bridges?

Another application is to identify easement and standing water conditions that prevent power utility crews from restoring electricity. Hazardous material leaks are a real concern; What's that sheen on the water? diesel? chemical? sewage? and where is it coming from? Are those propane tanks floating away?

Another use is to identify stranded livestock. Strategic SA can be used to inform the public about the flood, the impact on individuals or their relatives, or why evacuation orders are in place, especially if data are readily available on a social media site.

Detailed or Structural Inspection

The detailed or structural inspection mission is about experts examining built structures via either a quick look or a formal examination. One example is the examination of levees for signs of overflow (over the top) or for seepage (indicating incipient collapse). The most informative imagery is dependent on the structure and damage, and thus it is helpful to have an expert with the UAS team to direct the flight.



Lines in blue=path generated by software planning package; lines in white=progress of the actual flight

Figure 5. Lawnmower scan path for a UAS over a neighborhood affected by Hurricane Harvey

The flight may require more elevation (oblique) views than plane (nadir) views. Three-dimensional (3D) reconstruction is generally not used for the quick assessment.

This type of inspection is generally performed 10 feet (3 meters) away from the structure, which can be very challenging due to poor global positioning system (GPS) signals and wind shear. While some platforms have obstacle avoidance mechanisms, these mechanisms may be unreliable in such challenging conditions.

Ground Search and Rescue

In this mission, the UAS is generally assisting with the search for a missing person, object, or scene that is on the ground. In a flooding event, victims may have been swept away by the flood and the ground search is conducted after the waters have receded. For this mission type, high-resolution images are the most valuable, as video may be too difficult to freeze frame or lose resolution when paused.

A thermal payload may not be a silver bullet for finding either a survivor or a body, because foliage blocks any infrared signal. It is also important to note that imagery must be geotagged so that responders can go to the right location after the fact. In general, it is difficult for people or computer programs to interpret images.

The altitude at which an image was taken and the field of view (FOV) of the camera are necessary to understand the resolution and scale of objects in an image. Unfortunately, while most UAS systems embed the geographical coordinates of the UAS into the image, helpful attributes such as the altitude, FOV, and angle of the camera are not.

Water Search and Rescue

Water search and rescue is typically associated with a marine incident, although for a flood this includes a swift water rescue. A water search may be combined with a ground search for a victim after a boating accident on a lake where they possibly swam to shore, or a flood where a survivor may have been swept away but climbed out.

A missing person search in water requires high-resolution images. Thermal imaging may be the most reliable means to find a survivor in water, given that victims may present a small or partial profile and that waves and light reflection on the waves may confuse reviewers.

As with ground searches, any imagery must be associated with a geographical location, which is referred to as geotagging the image, so that responders can go to the right location; the altitude and FOV of the camera are also required to help with image analysis.

Debris, Flood Estimation, and Damage Assessment

Debris, flood estimation, and damage assessment is more detailed than general reconnaissance and more focused on documenting boundaries of an event, counting affected houses, and relating the current state of the area to the prior conditions. This type of assessment can enable drainage experts to confirm flood inundation maps and determine causes of variances (e.g., a fallen tree acting as a dam).

The mission might enable rapid volumetric estimations of debris after the flood recedes. It can also document land use and drainage issues to be resolved later.

This mission can be accomplished with real-time video and imagery (e.g., the drainage confirms that the flood boundary matches expectations) or with photogrammetric mapping for formal analysis of the extent of the flood.

Tactical Situation Awareness

Tactical SA uses a UAS to help the rescue team asses the condition of roads or bridges ahead to decide where to go from their current location. It also permits overwatch of teams or canines, or in swift water rescue oversight of floating debris that might jeopardize crews in boats, thereby increasing responder safety. Use of UAS for tactical SA is a common practice with the Florida State Emergency Response Team (SERT). UAS also has a place in traffic monitoring and detour routing efforts, providing needed viewpoints for transportation planning.

Delivery

This mission is for the UAS to facilitate delivery of material to any location. However, extreme care is needed when flying near people because operators tend to lose depth perception and may get far too close to objects and people. In addition, some platforms or payloads may not be able to maneuver safely for this mission type; something hanging off a small UAS changes the dynamics of the vehicle, creating a pendulum effect, so it may behave and move unpredictably.

MISSIONS BY PHASE

While the previous section introduced the seven categories of missions, it may be more helpful to think of these in terms of which missions appear during the disaster lifecycle. While there are many different models of disaster lifecycles, this document will use three phases: prevention/preparedness (before a flood), response and mitigation (during the event), and reconstruction and recovery (after evacuation orders are lifted). Table 1 lists the mission categories for each phase.

During the **Prevention/Preparedness** phase for a flood event, UAS can be used to periodically fly to establish conditions or can be flown immediately before a flood. Given the low cost of UAS, there may be no economic barrier to surveying areas every 3 months. In an area with a high rate of suburban development, frequent flights could allow agencies to become aware of potential problems while it is straightforward and cost-effective to fix.

Table 1. UAS missions by disaster phase

Prevention/Preparedness Before the Flood Crests	**Response and Mitigation** During the Flood Event	**Reconstruction and Recovery** After Evacuation Orders are Lifted
• Strategic Situation Awareness, Survey, and Reconnaissance • Detailed or Structural Inspection	• Strategic Situation Awareness, Survey, and Reconnaissance • Detailed or Structural Inspection • Debris, Flood Estimation, and Damage Assessment • Water Search and Rescue • Ground Search and Rescue • Tactical Situation Awareness • Delivery	• Strategic Situation Awareness, Survey, and Reconnaissance • Detailed or Structural Inspection • Ground Search and Rescue

While pre-event flights focus on geospatial attributes, such as the condition of drainage structures or use of the true state of the terrain to predict flood effects (Mardiatno et al. 2015, Özcan and Akay 2018), UAS with appropriate sensors can provide additional information. For example, they may soon be able to determine soil moisture (Dai et al. 2018), which, coupled with projected rainfall, should produce a more accurate prediction of flooding.

The primary missions for the Prevention/Preparedness phase are strategic SA, survey, and reconnaissance and detailed or structural inspection. Either mission may use real-time video or collect images for photogrammetric mapping.

During the **Response and Mitigation** phase for a flood, UAS can be used to reach areas that cannot be accessed by normal means, when satellite imagery would be too low resolution or takes days to obtain, or where manned aircraft would be too expensive. However, UAS do have limitations.

For example, as seen with Hurricane Harvey (Fernandes et al. 2018) and as noted by (Restas and Dudas 2013), UAS would not be able to fly in significant rain and thus cannot guarantee coverage. Another limitation is the flood itself may limit landing zones and thus prevent complete coverage with small UAS.

On the other hand, UAS offer many advantages. As shown with Hurricane Harvey (Fernandes et al. 2018) and the 2011 Thailand floods (Srivaree-Ratana 2012), UAS provided overviews of the extent of flooding and its impact. A UAS assisted in determining the fastest route to cut a bypass channel to relieve flooding from the Oso, Washington, mudslide (Murphy et al. 2015).

Cubber et al. 2014 were able to use a UAS to determine why flood mitigation was not working: a farmer was diverting the drainage system. Software can now segment floods from land, as research indicates (Gornea et al. 2016, Rahnemoonfar et al. 2018), which can help with planning.

The missions for the **Response and Mitigation** phase are likely to be flown with an expert due to the time pressure for actionable information. The missions are unlikely to involve photogrammetric mapping because moving water interferes with the image stitching process and because the operations tempo favors an “expert’s eyes-on” strategy.

The missions are typically on the order of 8 to 12 minutes long, reflecting both a “see what you need to see; then, move on to the next important area” operations tempo and the limitations of flying within the visual line of sight.

The primary missions for the **Reconstruction and Recovery** phase are detailed or structural inspection and ground search, although there may be strategic SA, survey, and reconnaissance flights for the general public. Delivery has been discussed as a possible mission for sustaining communities that remain disconnected but has not been demonstrated in the US.

Using a small UAS to estimate the volume and type of household debris has been attempted, but trees interfere with the necessary views to make this practical; in addition, agencies may have existing contracts with firms to provide that assessment.

PRIMARY USE CASES

Primary UAS use cases for flooding events are summarized below.

Exploit low-cost UAS. Any mission that can be performed with a video camera can be conducted using a platform thatcosts approximately $1,000 and has 20–25 minutes of endurance. As shown in multiple responses, and especially Hurricane Harvey, missions have a short duration of 8–12 minutes as experts quickly see what they need to see in order to make a decision.

The smaller platforms have inexpensive batteries that can be charged from a car inverter rather than a generator. The small size of the UAS and the ability to carry multiple batteries and recharge while driving to the next location means that a team can carry two or more UAS in a vehicle for redundancy and work from dawn to dusk. Therefore, there is no compelling reasoning to buy a more expensive, longer endurance platform, especially for agencies just starting a program.

Consider the extent of coverage and types of missions needed before deciding on using a UAS over a manned asset. If there is a significant area to be covered, it may be more effective to use manned aircraft. While in theory, a UAS should be able to completely cover an entire area by flying a portion, then moving, flying, and so on, there may not be take-off and landing zones, especially for fixed-wing assets, for all sub-areas, or it may take hours to drive (or boat) from one sub-area to another.

Apply the COPIED heuristic to select the UAS platform for a mission. COPIED stands for **C**onstraints, **O**perator factors, **P**enetration or distance (e.g., visual line of sight), **I**nformation that the UAS provides to whom and when (e.g., video imagery streaming over FirstNet), the **E**nvelope in which the robot works (e.g., altitude, weather, expected range, density of manned assets), and the **D**uration (e.g., typical 8–12 minute missions or 30-minute mapping missions).

Fly before the flood crest to establish accurate “before” conditions. This can help update any topological data needed to project flooding. It can help identify potential vulnerabilities, such as new homes that may not have a flood-proof emergency route. UAS are such low cost, it should be possible to fly routinely in most areas.

Expect to use rotorcraft rather than fixed-wing UAS. Fixed-wing UAS often have very restrictive takeoff and landing zone requirements (e.g., an open, unflooded space the size of a soccer field). Rotorcraft can fly more reliably at lower altitudes and they can hover and stare, which is helpful in estimating the flow rate of flood waters.

Expect to fly within the visual line of sight in populated areas during the response and mitigation phase. Flights in urban and suburban regions will normally be visual line of sight for safety reasons; there is typically dense helicopter traffic, often below 200 feet. For example, life-flight helicopters may not waste time going up to a high altitude but instead zoom low and fast. Military, customs, and border patrol aircraft may also be operating at the tree line or running a river.

In densely populated airspace such as that seen with Hurricane Harvey, the UAS pilot will need a visual observer to keep a sharp look out for air traffic and have a plan for rapid descent to get out of the way. Rural areas see less helicopter air traffic due to the costs and logistics of getting a helicopter to fly to remote locations. However, being in a rural area does not guarantee a sparse airspace.

The missing person search after the Blanco River floods saw multiple private helicopters searching for signs of victims and flying under 100 feet, and the rural Oso mudslides were next to a military jet training route with pilots periodically deviating “one mountain over.”

Deploy a UAS from a boat or airboat, but with care. Boats are often the fastest way into a flooding disaster area. With Hurricane Harvey, this was extremely helpful in assessing the flooding impacts in the suburban mega-developments.

Send agency experts (and social workers) with the UAS team or prepare them to answer general questions. UAS are a magnet for the population; people will come over to find out what is going on and to ask questions about the response, how to get help, etc.

Even if there is cell coverage, it may be appropriate to have a county or agency representative with each UAS team conducting surveys to answer questions from citizens. Having a social worker or country representative is also helpful to diffuse any public anger over lack of responsiveness; people in the middle of a disaster do not like to be told to call a 1-800 number, even if their concerns are not life-threatening.

In general, wearing vests and identification (ID) tags and driving in an agency vehicle diffuse fears of privacy violations, and the public is generally supportive of seeing their state or local government use technology for a disaster.

Expect to send out experts with the UAS team for time-sensitive missions during the initial portion of the response phase. Preprogrammed mapping flights may not get the right viewpoints for structural inspection, investigation of the causes of flooding, or overwatch types of missions; real-time streaming may not work. Thus, the UAS team may not get the right information or have a way to get the right information to the right person.

An expert can look at real-time footage and direct the flight; then, call on a radio or cell phone with any immediate findings.

Have a UAS expert work directly with the Air Operations Branch. This simplifies airspace coordination. Route requests through a centralized incident command system where the air branch can assign tasks to manned or unmanned assets (e.g., some missions could be better executed by the Civil Air Patrol than a UAS). This centralization also helps identify opportunities to share data.

Have a dedicated data management policy and manager. The geographic information system (GIS) team won’t be able to handle the additional workload and high-resolution imagery from a single 20-minute flight that can run around 2 gigabytes (GB), so prepare for both data storage (get a hard drive) and the extra manpower.

Any deployment should have a data management policy that specifies ownership of the data (i.e., if a volunteer is flying, all data belongs to the agency and cannot be released without the agency’s permission). The policy should also specify chain of custody procedures.

Don’t expect UAS to reduce manpower; they may actually increase the number of people working in a response, but they should provide capabilities that were not possible or economical any other way. It is likely to be a better use of experts’ time to have a UAS team work for them, rather than expect an expert to fly the UAS, plus take care of charging, keeping up with regulations and airspace, etc.

If you want a single image of a neighborhood or the terrain surrounding a structure or road, consider options such as Hangar 360 or DJI Panorama rather than a preprogrammed flight over the area, then having to upload the data to a post-processing site, etc. These applications automatically rotate the UAS in place and take digital images, then construct a 360-degree panorama.

Volunteers may not be adequately prepared for disaster response, in terms of familiarity with regulations, personal safety, or advanced flight skills.

Plan to fly daily to monitor the dynamically changing event. This means considering access, permission, and manpower availability.

Prioritize vulnerable locations. It may take 2 to 4 hours to reach a location, so there won’t be time to map an entire county with a small UAS during the immediate response phase (even if there are suitable landing zones).

Don’t expect to use UAS for homeowner property damage (e.g., measuring the waterline on a home). Many homes are in neighborhoods with trees that block the view or it is difficult for the UAS to get an elevation view of the house. Consider using a vehicle- or boat-mounted mapping system such as GroundVu instead.

CONCLUSIONS

Small rotorcraft unmanned aerial systems have become increasingly common before, during, and after flooding disasters. A commonly used platform that retails for approximately $1,000 can perform six of the seven basic missions for flood events.

The low cost of current UAS combined with the best practices that have emerged since their first introduction in 2005 with Hurricane Katrina offer a solid foundation for rapid adoption by agencies.

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