Best Practices to Reduce Fatigue in Small Uncrewed Aerial Systems Pilots*

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***Abstract*— Just like with crewed aviation, fatigue is a real problem for Small Uncrewed Aerial Systems (sUAS) pilots. However, unlike crewed aviation, there are no regulations and few explicit guidelines available for mitigating fatigue when piloting sUAS'. This is particularly relevant for piloting sUAS' during disaster response. This paper presents a framework of aspects contributing to human performance and fatigue and some best practices for mitigating that fatigue before and during disaster response.**

I. Introduction

Just like with crewed aviation, fatigue is a real problem for Small Uncrewed Aerial Systems (sUAS pilots). For instance, after only a day at one deployment (Hurricane Harvey), pilots showed a level of fatigue impairments equivalent to those of alcohol intoxication at 0.05%, which is above the legal limit for crewed aviation pilots (0.04%)[1]. A 2019 human-robot interaction study sponsored by the National Science Foundation of 16 experienced pilots at Hurricane Harvey, Kilauea volcano, and Hurricane Michael showed that all pilots showed fatigue early in the deployment—even with regular shifts and sleep—and never really recovered [2]. This type of fatigue increases the possibility of human error and can compromise the teams' ability to accomplish the goals of the mission successfully. For instance, in an overnight exercise simulating a disaster response, the number of skill-based errors in providing data from sUAS missions increased over the course of the exercise (see Figure 1). These types of errors could involve either data gathered from the sUAS being lower quality or lost, data taking longer to gather, the pilot of sUAS possibly violating regulations, or having a collision or crash, etc.

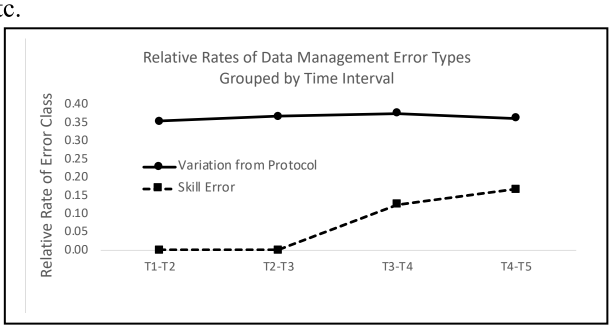

Figure 1. Rates of error types in overnight disaster simulation exercise.

When robotics and automation are integrated into security and rescue operations, they are always a part of a bigger mission and system. Thus, the specific tasks will differ for each type of operation, often for each specific deployment and even for the phase of deployment. However, given that humans are involved in the operation and management of the devices (robotics, machines, systems, etc.), to increase the successful completion of any mission, not only does the human-machine interface need to be considered, but also the entire human-system interaction (HSI). In this paper, we present an important part of HSI for the deployment of small sUAS during disasters—specifically, the effects of fatigue and best practices for mitigating these effects.

There are many sources and causes of fatigue [3, 4]. As anyone who has been deployed to a disaster, fatigue will occur and cannot be completely avoided. Responders often have to drive for an extended period of time to get to the deployment site; there are often very long, stressful days of work and sometimes short night's sleep. These are all elements of the deployment that can obviously result in fatigue and are associated with the environmental constraints of the deployment. There are other elements of the deployment that can also contribute to fatigue and stress, such as the type of and familiarity with the task being performed, the equipment being used to perform the task, as well as the skills, recent practices, and cognitive and requirements of the person performing that task. For instance, if the task is a particularly difficult one, and someone who does not have much experience with that task is performing the task with a drone they have not used many times before, that person will experience much more fatigue while performing that task than someone who was familiar with the task, using a drone they flew often. Now imagine a less experienced person with the task who has not had much sleep in the last 24 hours and is working with an unfamiliar team who may not know the signs of when that pilot is stressed or fatigued. Anyone who has deployed can understand how these factors can compound and increase the likelihood of mistake, and possible an extremely consequential one—there is also research to substantiate this (but in other domains [5, 6]). This vignette does not include some of the other stressors such as wearing uncomfortable personal protection equipment such as gas masks or protective clothing, or the basic physiological stress of being at a disaster.

The challenge becomes identifying systematic methods of attending to and mitigating these factors so pilots and the squads they are in have the highest likelihood of positively contributing to a successful mission. Clearly, more research is needed that can inform standards and procedures, but

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fortunately, there are things you can do now! This paper will present some of those best practices.

II. Three Groups of Factors to Consider

Before we specify some best practices, it's important for the reader to have a bit of background regarding human behavior. As a general rule of thumb, there are three major groups of factors that can be used to predict human behavior (including human error)—the task, the person, and the context [7, 8]. These groups are useful for considering when identifying individual sources of fatigue as well as those factors that may interact to increase levels of fatigue more than the two factors by themselves.

A. Task

During a disaster response, sUAS are leveraged for different deployment needs, e.g., mapping the area to ascertain the amount of damage, search and rescue, measuring air quality, finding hot spots in fires, etc. Many of these needs require different types of tasks (and often corresponding software) that must be performed by the sUAS squad [9].

For instance, for mapping, the pilot typically would use mapping software to fly a predetermined area defined by the Incident Command Center (ICC). This task takes some training and experience to get set up, but once the drone is in the air, it requires little effort on the part of the pilot. The drone takes images as prescribed, and when the task is over, the squad delivers those images to the ICC [9].

Conversely, for search and rescue, the pilot is looking for people who are in distress to tell local authorities where to go to rescue them. This can occur during daylight hours or at night using heat-sensitive vision. This task requires the pilot to not only attend very closely to everything the drone is doing but also look at the images as they are being produced [10].

These examples are provided to illustrate that tasks can differ remarkably in their difficulty, complexity, and frequency. For instance, mapping tasks are regularly done in disaster response; however, measuring air quality is a more unusual task and was performed for the first time during the response to the Kilauea volcano eruption. The more difficult, complex, and infrequent a task is, the more pilots and sUAS squads must allocate cognitive resources to perform the task—contributing to fatigue [10].

B. Person

Each individual pilot and squad member contributes their own personal skills and strengths (as well as their own challenges) to the successful completion of a mission. Some of these differences (personality, IQ, etc.) are not really attributes that can be "mitigated." However, there are other attributes that are generalizable to most people and are important to consider when looking to mitigate fatigue.

One of these attributes is how much experience someone has *with disaster response*—note this does not refer to experience with sUAS or their squad but with actual disaster response. Disaster response involves different missions, procedures, and operations tempo than a pilot may be used to. For example, the skills used by a fire rescue department for fighting structure fires may not match the mission skills needed for mapping wide areas of damage with specialized software. The ICC may require that all pilots follow the ICC's procedures and data management conventions, and these may differ from what the squad is used to. Another is someone's level of physical fitness, as fatigue tends to be worse and occurs more quickly with lower physical fitness [11]. Lastly, the amount of experience someone has with the type of tasks they are performing or the drone they are using during the deployment. Someone may have responded to many disaster deployments, but if they are performing a task or using a drone for the first time, it will likely require more cognitive resources than if they were experienced with that task and/or drone [12]. Again, this can remarkably contribute to fatigue.

An obvious but sometimes overlooked attribute of the person to consider during disaster deployments is how fatigued they are when they arrive at the disaster deployment site. In the case of a hurricane or flood, teams will often have two days' notice, which means they had two intense days of preparing for the disaster while simultaneously offloading their routine work and home responsibilities so that they may have gotten little sleep. Sometimes, squad members must drive a considerable amount of time with little rest to get to the deployment [10]. Other times, they may have flown from different time zones, and their body may not have adjusted yet. In situations such as these, it is likely that they are going to become fatigued more quickly during the deployment than if they arrive rested. Further, if they have consumed alcohol before the deployment, even if they follow the FAA "8 hours from bottle to throttle" guidelines, it is important to understand that alcohol interferes with restorative sleep [13]; these squad members will not initially benefit from whatever sleep they do get.

C. Context

Context essentially refers to everything other than the task and the person. This includes the physical environment and location, the influences of other people on the person performing the task (psychosocial context), and the tools people are using to perform the tasks.

1) Physical environment

When sUAS teams are deploying to disasters, the weather can be one of the primary contributors to fatigue associated with the physical environment. For instance, for hurricane deployments, squad are often working in hot and humid conditions with little to no access to air conditioning. This increases fatigue development as well as the possibility of heat injury (stress or stroke)[14]. However, responding to a disaster such as the Surfside condominium collapse can happen at any time of the year. Thus, in these cases, the physical environment may not be as big of a contributor to fatigue. In addition, other aspects of the general austere conditions can lead to fatigue. When working in the field, teams generally do not have access to restrooms, meals, or even chairs. They may be sleeping on cots or sleeping bags on the floor [15].

2) Psychosocial context

The impact individuals around a person have on their mental and physical state is often misunderstood and thus underestimated [16]. When sUAS pilots are working within a squad that is unfamiliar to them and/or critical and unsupportive of squad members' performance, pilots will have to allocate cognitive resources to managing their vigilance and reactions to this criticism or environment. This increases the cognitive resources required for the actual task of flying the drone and can likely result in fatigue developing more quickly. In contrast, when pilots are working with a familiar squad that has a culture where they "have each other's back" (e.g., notice potential issues/problems and help the pilot catch them before mistakes happen), the pilots can focus on the task at hand and be comfortable asking questions and asking for help [17].

The operations tempo (op-tempo) and pace of the deployment are two aspects of the context unique to disaster response that can impact the psychosocial context and can contribute to fatigue. With a regular and predictable op-tempo, squad and team members can adjust their rest and sleep schedules accordingly. However, this is much more difficult, if not impossible, when op-tempo is irregular or chaotic. This can not only increase fatigue but can cause frustration and irritation among those participating in the response. For squads who have not worked together long, this may contribute to a poorer safety climate, again contributing to fatigue.

3) Tools

For disaster response, there are multiple sUAS available, and these differ by the model of the drone, the software used, and the controller [9]. The software can vary based on the mission (e.g., mapping versus search and rescue), the drone selected may be based on availability or appropriateness for the external conditions, and the controller used is often determined by the pilot. These elements together create the human-robot interaction (HRI) for the sUAS. Contributors to fatigue can be the usability and effectiveness of the drone's HRI and the pilot's familiarity with the aspects of the drone system. For instance, displays that are not intuitive, have interactive elements that result in items on the display being obscured, or have regularly needed information buried under layers of menus can be frustrating and fatiguing to use—regardless of the pilot's experience with that system. HRI systems that do not support the prevention of typical/predictable errors (e.g., adjusting the current altitude before programming a flight) can also contribute to fatigue, as resolving errors requires additional time and effort.

D. Interactions

Individually, when looking to identify sources of fatigue for sUAS squads during a disaster response, it can help to consider aspects of the person, task, and context. These aspects can interact as well as described earlier in the contrasting vignettes of someone performing a difficult task who has little experience with the task versus someone performing the same task who is very experienced with the task. The pilot with less experience will likely experience more fatigue while performing the task than the more experienced pilot—illustrating an interaction between task and person. This can be exacerbated by an unsupportive squad—showing a three-way interaction.

E. Summary

Explicitly articulating the sources of fatigue is likely not going to be something that those responding to a disaster will have the time or inclination to do. At the same time, the task, person, and context "Triad" may be a sufficiently simple framework for considering sources of stressors and fatigue for disaster response.

III. Best Practices by Deployment Phase

After reading how the task, person, and context can contribute to the development of fatigue, any who have deployed to disasters may be asking, "But what about an experienced person using a new drone in a familiar squad? What happens then?" There are, without question, many different permutations of these major attributes, and this paper will not be able to address them all. However, from our research and experience, we have some best practices that include (either directly or indirectly) how and when these attributes interact to contribute to fatigue. A listing of these is also provided in Table 1.

A. Before the deployment

It is absolutely necessary to have squads that are truly trained and experienced *for disaster conditions.* Although many people who deploy to disasters use sUAS on a somewhat regular basis (e.g., firefighters using them to look for hotspots in large area fires), the conditions, timelines, and specific tasks are remarkably different during a disaster [9]. This requires specific and regular training for squads to be sufficiently informed and prepared regarding how using an sUAS for disaster response differs from that in their regular "day jobs." It is even better if the squads have worked together previously as then they are likely more comfortable backing each other up and noticing and alerting about any problems.

sUAS squads should work to be as rested as possible (noting that there are constraints to this with the travel required to get to the disaster response). This includes avoiding drinking alcohol before the deployment, as this contributes to fatigue by interfering with sleep.

B. During Operations

1) Incident Command/Team Leader

There are several things a leader can and needs to do to mitigate the impact of fatigue. For instance, if there is the possibility of night flights, the leader should hold a squad in reserve, so pilots do not have to work all day and then again through the night. The team leader/Air Branch commander should strive to give new missions or tools (e.g., sensors) only to the most experienced pilots, as these pilots will have more cognitive resources to contribute to learning the methods and goals. Whenever a new mission or sensor is required, the leaders should pause to perform a risk analysis on paper to determine if the potential risks outweigh the potential gains. The possibility of fatigue should be incorporated into this risk, particularly considering when in the deployment the mission will occur (e.g., if it is later, the likelihood for fatigue increases, thus increasing risks) and whether the mission is occurring after a long day of work.

As mentioned before, team leaders should remind the squads of the "8 hours bottle to throttle rule" and that alcohol interferes with restorative sleep. This can be included in reminders in daily briefings and after action reports.

2) Squads and pilots in the field

Within a squad, there are methods the team can use to mitigate fatigue. One method is having pilots alternate sorties between them to change up the cognitive demands. For instance, pilot 2 can be a visual observer on Sortie 1; then pilot 2 can be the pilot on Sortie 2, etc. Another method is to empower safety officers/visual observers to step in when they see that assistance is needed. This can best occur when the visual observer is also a trained pilot, so they will be more likely to know when assistance is needed. This is an example of how a good safety climate can mitigate fatigue and support a successful mission.

The consistent use of and adherence to verbal rehearsals, verbal protocols (formal checklists), and a sterile cockpit may not seem necessary when the squad is fresh and focused. However, when these practices and protocols are automatic and require little thought, they can support squad members' performance (e.g., reduce errors) when the team is fatigued. Team leaders and safety officers should adhere to verbal rehearsals and protocols, especially as the deployment continues and fatigue increases. This communicates its importance and reminds squad members to engage in these activities. Further, although adhering to a sterile cockpit can seem somewhat unnatural, when fatigued, people are more easily distracted from a task, and this can degrade performance. When a sterile cockpit is a common practice (i.e., automatic), squads will not have to use cognitive resources to remember to do this when pilots are more likely fatigued.

Consistent and constant quality control is paramount for sUAS squads in disaster response. The ultimate goal is to get data from the field to the ICC. To mitigate the likelihood of needing to redeploy to a location for a particular sortie, each squad should perform quality control after each sortie, particularly to make sure that they obtained the data! Having to redeploy for a particular sortie contributes to fatigue and increases the time required to send the data to the ICC.

Table 1. List of fatigue mitigation methods for sUAS and disaster deployment.

When	Who	Mitigation
Before Deployment	All	• Be as rested as possible. • Avoid alcohol before deployment.
During Operations	Incident Leadership	• If there is a possibility of night flights, hold the squad in reserve. • Give new missions or tools (e.g., sensors) to the most experienced pilots. • With a new mission or sensor, pause to perform a risk analysis. • Remind squads of the "8 hours bottle to throttle rule" & that alcohol interferes with restorative sleep.
During Operations	Squads & Pilots	• Alternate sorties between pilots to change up the cognitive demands. • Empower safety officer/visual observer to step in when they see that assistance is needed. • Consistent and constant quality control is paramount for sUAS squads in disaster response. • Consistent use of sterile cockpit, verbal protocols, and pre/post flight checklists.

IV. Conclusion

In this paper, we present some best practices we have developed based on our experience and research in disaster response with sUAS. At the same time, we know that this listing is going to be incomplete, given that each disaster and response team is unique. Thus, we have provided incident command leaders, squad leaders, and squad members with a method for parsing attributes of the disaster response that can contribute to human performance. These attributes are the task, the person, and the context. These can be leveraged as a guide to identify potential, unconsidered sources of fatigue that need to be mitigated.

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