Influencing Factors for Use of Unmanned Aerial Systems in Support of Aviation Accident and Emergency Response

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Abstract—The purpose of this research paper was to examine the influencing factors associated with the use of unmanned aerial system (UAS) technology to support aviation accident and emergency response. The ability of first responders to react to an emergency is dependent on the quality, accuracy, timeliness, and usability of information. With aviation accidents such as the Asiana Airlines Flight 214 crash at San Francisco International Airport, the ability to sense and communicate the location of victims may reduce the potential for accidental passenger death. Furthermore, the ability to obtain information en-route to an accident may also to assist to reduce overall response and coordination time of first responders (e.g., Aviation Rescue and Firefighting [ARFF]). By identifying and examining current and potential practices, capabilities, and technology (e.g., human-machine-interface [HMI], human factors, tools, and capability modifiers) a more comprehensive model of the influencing factors is established to further support the growing body of knowledge (i.e., safety, human computer interaction, human-robot systems, socio-economical systems, service and public sector systems, and technological forecasting). A series of recommendations regarding the technology and application are provided to support future development or adaptation of regulations, policies, or future research.

Index Terms—unmanned aerial systems, UAS emergency response, UAS aviation accident response, UAS application, UAS HMI, UAS disaster response, UAS situational awareness

I. INTRODUCTION

The purpose of this research paper was to examine the influencing factors associated with the use of unmanned aerial system (UAS) technology to support aviation accident and emergency response. The ability of first responders to react to an emergency is dependent on the quality, accuracy, timeliness, and usability of information [1]. With aviation accidents such as the Asiana Airlines Flight 214 crash at San Francisco International Airport [2], the ability to accurately sense and communicate the location of victims may reduce the potential for accidental passenger death. Furthermore, the ability to obtain information en-route to an accident may also to assist to reduce overall response and coordination time of first responders (e.g., Aviation Rescue and Firefighting

[ARFF]) [3]. Identifying and examining current and potential practices, capabilities, and technology (e.g., human-machine-interface [HMI], human factors, tools, and capability modifiers) supports the development of a more comprehensive model of the influencing factors to further support the growing body of knowledge (i.e., safety, human computer interaction, human-robot systems, socio-economical systems, service and public sector systems, and technological forecasting). Finally, a series of recommendations regarding the technology and application are anticipated to guide future research and support future development or adaptation of regulations and policies.

A. Perceived Need

The application and utility of UAS is rapidly expanding based on the development and advancement of new technologies, operational processes, and interoperability achievements [4], [5]. As the capabilities, limitations, and considerations associated with these systems are better understood, the regulatory environments become more defined [6], [7]. Stakeholders in this emerging industry have expressed a belief that an over regulated operational framework (e.g., U.S. national airspace system [NAS]) will lead to diminished innovation, business, and capability [8]-[10]. Achieving a clearer understanding of the primary factors that drive legal developments (i.e., current and future) is anticipated to improve the dialog among industry stakeholders, regulators, and policy-makers.

B. Overview

This research paper represents the examination of the case for UAS use in emergency response efforts focusing on aviation accidents. The paper contains a discussion of considerations as they relate to an aviation accident response framework, advantages of integrating UAS capabilities, and the legislation and policy issue associated with their use. Examples of existing and developing technology to enable this task are explored, including automation, human-machine interface (HMI), air vehicle platform (i.e., unmanned aerial vehicle [UAV]) performance, sensors, and situational awareness. Finally, several research, technological, and policy recommendations will follow outlining a path to achieve

the integration of UAS into aviation accident search and rescue, recovery and investigation.

II. PRACTICES, CAPABILITIES, AND TECHNOLOGY

A. Emergency Response Framework

To ensure effectiveness and rapid response, those in command of emergency response efforts (e.g., Emergency Managers) require a flexible framework for the capture, processing, and dissemination of information. Such flexibility should support innovative and dynamic actions, shared decision making, and the ability to complement teamwork, management, and improvised response [11]. Creating an accurate model of the scenario through the capture, analysis, and presentation of the information relating to the emergency (i.e., establish accurate situational awareness) provides significant opportunity to improve the effectiveness of response and reduce the potential for responder injury [12]. A common theme exhibited by researchers and experts is the criticality of supporting practices, capabilities, and technology be used to support flexibility and accuracy, rather than causing interfere or obstruction in the formulation and implementation of appropriate responses.

B. UAS Legislation and Regulatory Environment

The ability to use UAS for disaster relief or other emergency services in the U.S. is extremely limited by the Federal Aviation Administration (FAA). According to its *Federal Register Notice FAA-2006-25714*, "The current FAA policy for UAS operations is that no person may operate a UAS in the National Airspace System without specific authority. For UAS operating as public aircraft the authority is the [certificate of authorization or waiver] COA, for UAS operating as civil aircraft the authority is special airworthiness certificates, and for model aircraft the authority is AC 91-57," (p. 5) [13]. Essentially any conduct of UAS operations (other than hobbyist use of a model aircraft), must receive either a special airworthiness certificate (e.g., restricted or experimental), a COA, or be a FAA UAS official test site participant. Guidance for special approval is provided in *Notice 8900.207, Unmanned Aircraft Systems (UAS) Operational Approval* (cancelled, updated by 8900.227).

The potential users of UAS in the U.S. face regulatory and legislative challenges on many fronts. UAS are expected to conform to aspects of 14 CFR Part 21, which regulates the certification of aircraft, products, and parts as well as standards for airworthiness certification. Advisory Circular 45-2 designates the required markings for UAS to include registration numbers. Advisory Circular 91-57 describes the differences between hobby use and non-hobby use of small aircraft (typically what would be considered a small UAS [sUAS], sub-55lb platforms), and operating restrictions thereof.

Several orders have been implemented by the FAA as well including:

- Order 1110.150, Small Unmanned Aircraft System Aviation Rulemaking Committee
- Order 8130.2, Airworthiness Certification of Aircraft and Related Products
- Order 8130.20, Registration Requirements for the Airworthiness Certification of U.S. Civil Aircraft
- Order 8130.34, Airworthiness Certification of Unmanned Aircraft Systems

These documents provide guidance on the type of research and certification standards that remain to be discovered and/or put into place in order to fully integrate UAS into the U.S. National Airspace System (NAS) [14]. The most comprehensive outline of FAA requirements and plans for allowing for UAS operations in the NAS are described in its *Integration of Civil Unmanned Aircraft Systems (UAS) in the National Airspace System (NAS) Roadmap* document. However, it is clear that this process is still many years away from fruition [15].

Further obstacles to UAS integration and their potential use in emergency situations can be found in state and local legislation. According to the National Conference of State Legislatures (NCSL), "In 2013, 43 states introduced 130 bills and resolutions addressing UAS issues. At the end of the year, 13 states had enacted 16 new laws and 11 states had adopted 16 resolutions" (para. 1) [16]. Moreover, several local municipalities, e.g. Charlottesville, Virginia and Syracuse, New York, have adopted further restrictions such as prohibition from city purchases of UAS and other operational restrictions [17].

Lastly, significant concerns about privacy and data collection have surfaced in the U.S. The FAA added a requirement for privacy protection plans in their call for test sites. Influential civil rights groups such as the American Civil Liberties Union (ACLU) and Code Pink have voiced their concerns through protest rallies and calls on legislators to take action to protect personal privacy. An example of the influence of such groups, the City of Seattle Police Department abandoned plans to use UAS in local law enforcement after vocal protests at a hearing proposing the use of the systems.

It is apparent that until the legislative, regulatory, and privacy issues surround UAS adoption are resolved, there will be little chance of the use of such systems in first response situations. Yet it is necessary that research into their use in these situations must move forward so as to identify the best practices in their use in emergency scenarios. While the legal hurdles remain in place, researchers should continue their efforts to develop systems, uses, and procedures through the use of test sites or COAs in order to be ready to utilize UAS to assist rescue personnel as soon as such operations are authorized [18].

III. RECENT ADVANCES AND CAPABILITY MODIFIERS

A. HMI and Human Factors

Very often, designers create controls and displays that work perfectly in the lab but fail miserably in a real world setting. The common expectation is that humans will "learn to adapt" to the controls and displays provided with a system and, with proper training and familiarization, will become proficient in system use over

time. From a human factors perspective, this is absolutely the wrong approach to take when designing HMI, but is often the fallback position taken when proper design principles and test and evaluation are not conducted sufficiently.

As UAS technology develops and becomes more capable, it will also become more complex in every way, and the need to implement advanced technology and automation as a way to mitigate control issues becomes more apparent. The UAS of the future will be a design that is technologically advanced, highly intuitive, highly automated, and should be interoperable with a number of other systems. Despite the name given to these "unmanned" systems, it is essential to remember that human operators are still involved in the control loop and operation of the vehicle (e.g., man in the loop or man on the loop), as well as in the interpretation of video and sensor data being collected and transmitted by the vehicle.

Four major issues facing HMI design in UAS that result in design inadequacies are: 1) lack of standardization for UAS HMI or Ground Control Stations (GCS), 2) lack of optimization of HMI information presented to the user, 3) lack of HMI flexibility and adaptability, which is essential for optimization of workload and situational awareness, and 4) sensory deprivation and isolation of the human operator. Lack of standardization across different UAS HMIs leads to extensive training time for one system and lack of ability to easily transition to other systems, if needed. Lack of optimization of information presented leads to difficulty in interpreting operational and system information needed to support decision making and situational awareness under high stress, high stakes situations. Lack of HMI flexibility and adaptability, often related to poor displays and poor implementation of automation, leads to high workload and poor situational awareness. Finally, perhaps the most important deficiency present in UAS HMI design is the lack of basic sensory cues normally used by a pilot on board a manned aircraft (e.g., aural, tactile, and vibrational). Sensory cues such as the sound of the aircraft as it accelerates, or the "flying by the seat of your pants" sensation of g-forces that act as confirmatory information during operational maneuvers all add to the realism, enhanced situational awareness, and sense of presence when operating a manned aircraft. When examining current UAS HMI designs, one must consider why these same cues suddenly become irrelevant in comparison to the operation of a manned aircraft. Currently, these cues are missing and consideration should be given for their incorporation into the GCS of the UAS HMI.

Designing HMIs that consider the end user can significantly improve operational effectiveness. Designing with the user in mind means designing HMIs that are functional, intuitive, and easy to understand, presenting information in a way so operators can easily extract relevant information when needed, process that information, and manipulate the system in a safe, efficient, and productive manner. With the new capabilities present in current interface technology and software, it is now possible to design functional, intuitive interfaces that take advantage of the available cues and impart the necessary information to maintain high levels of situational awareness needed for safe, efficient, and effective control of unmanned vehicles [19].

B. UAS Designs and Technology

Currently there are limitations in terms of the performance of sUAS in terms of their endurance, speed, range and maneuverability. These limitations of sUAS exist because of limited size of the fuel systems that can be incorporated into the aircraft. A large portion of the total mass of many electric powered small UAVs is the rechargeable battery source. Anton [20] investigates the possibility of harvesting vibration and solar energy in a mini UAV. Piezoelecric patches placed at the root of the wings and a cantilevered piezoelectric beam installed in the fuselage have been studied to harvest energy from wing vibrations and rigid body motions of the aircraft. Similarly thin film photovoltaic panels attached to the top of the wings have shown promising results for harvest energy from sunlight [21].

Morphing wing concepts have been shown to reduce drag as they burn fuel, thus improving the range and endurance of sUAS [22]. Nehme, Scott, Cummings, and Furusho [23] introduce the concept of futuristic heterogeneous unmanned systems where multiple ground, air and underwater based systems work collaboratively to achieve a goal. Using multiple platforms provides the flexibility in terms of gathering information from multiple sources and points of views. Also a variety of sensors can be incorporated in different vehicles. Human factors associated with UAV operator control situational awareness has been addressed by the Air Force Research Laboratory's Human Effectiveness Directorate (AFRL/HE) [24]. Further improvements in the UAV performance has been shown for vertical takeoff and landing (VTOL) UAVs. The ducted fan UAV aerodynamics in forward flight has been determined to influence static thrust performance as well as the duct pitch moment, pressure distribution, and overall flight characteristics. Graf et al. [25] performed experiments to show the enhancement in controllability of ducted fan UAVs with duct lip mounted control devices [26]. Similarly, a few other areas of future improvements have been identified in the UAS integrated roadmap by the department of defense [27]. These are some of the examples of technological and performance improvements that could help improve the range, endurance, and maneuverability of UAVs. With these improvements, the UAVs have the potential to become one of the most suitable platforms for disaster recovery in aviation accidents.

C. Sensing and Processing

The success of any disaster recovery mission relies on an asset being in the right place, at the right time, with the appropriate sensors, and a method to transmit or pass data. This is particularly true in the realm of aviation accidents where the terrain, weather, remoteness and emergency

signal types varies significantly. Even if the right place and right time requirements are met, a UAS will be ineffective without the correct suite of sensors and the capability to pass information to the operator. There are several phases of an aircraft accident search and rescue response. However, the initial "find" phase is critical to the mission and in many cases, the timeline associated with it will determine whether the mission ends in rescue or recovery [28]. Fortunately, aircraft emergency locator transmitters have advanced significantly over the past decade to include digital transmission of personal, aircraft and location data at 406MHz. However, this equipment is more expensive than traditional 121.5MHz ELTs and is not mandatory on all aircraft [29]. The COSPAS-SARSAT satellite constellation, which monitors 406MHz transmissions, no longer processes the 121.5MHz signals. These signals are the only emergency locator transmitter (ELT) capability in thousands of aircraft. The reliability of such transmissions can also be unreliable with the newer ELTs shown to transmit in 81% to 83% of accidents and older 121.5MHz ELTs only 73% [30]. Clearly, reception of the emergency signal and determining its location is critical.

Various sensors may be employed on one UAS or on multiple aircraft, which combine their data to form a single picture of the situation (i.e., sensor fusion). Since ELT signals are omni-directional and strength decreases by the inverse square of the distance, UAVs directed to a general location should receive a significantly stronger signal than satellite or ground station receivers farther away [31]. Multiple UAVs can triangulate the signal or relay the signal information if sent in the digital format. In cases where ELTs are not activated, or not transmitting for various reasons, low light and infrared sensors can be used to search for the aircraft location. Fortunately, the technology and miniaturization advances for many sensors in the low light and infrared wavelength have significantly decreased cost and physical dimensions. This allows use in many group sizes of UAS (e.g., groups 1 to 5) [32]. Often aircraft accidents include ignition of unused fuel which will heat the accident area and remain above the ambient temperature for several hours after visual indications of combustion are no longer present. In these cases, infrared and near-infrared sensors employed in a wide-area mode may be able to detect the heat source from a significant distance. These sensors have also proven invaluable in personnel searches since the typical body temperature will stand out against most ambient backgrounds. Another sensor that a UAS could employ is a cellular phone receiver. Since cell phones transmit at relatively low power, reducing the range between the transmitter and receiver may allow signal reception and processing. Regardless of the sensor capability, the data collected must be processed, stored and/or transmitted.

Onboard data processing and automation will be a key enabler for effective UAS operations in this environment. The ability to process large amounts of data onboard a UAS would greatly reduce the required transmission bandwidth which, in many cases, is extremely limited [33]. Onboard signal detection, processing, geo-location, reduction, compression and ultimately transmission must be a seamless process. Due to the assumed remote location which a UAS or team of UAS would be utilized, it is unlikely that a continuous wide-band full motion video feed would be practical or possible. The most promising technology to overcome this limitation is automated on-board processing; processing that occurs on the UAS, set by pre-mission defined parameters, and only transmitting data applicable to the mission. Once significant information is identified, the control center can update the UAS mission tasks, order more fidelity, dedicate more bandwidth or even open direct lines of communication.

D. FAA Designated Test Sites

Flight testing is a critical component of introducing new aircraft designs, systems, or applications. The flight test process allows for collection of data while the vehicle is in flight. These data can be aircraft performance data, subsystem performance data, and aircraft control characteristics and qualities. These data allow for verification of operational procedures and the establishment of safe flight envelopes. Most importantly, flight testing establishes the body of evidence necessary to ensure compliance with published aviation regulations [34].

Leaders within the U.S. FAA have selected six test sites to provide UAS operational experience and research knowledge to ensure safe integration into the NAS [35] . The selection of these test sites was in direct response to the lack of scientific evidence needed for risk quantification and identification of yet to be defined safety standards necessary for safe integration [36]. Additionally, the U.S. Congress mandated the establishment of a test site program. This mandate was recorded in the *FAA Modernization and Reform Act of 2012.*

The six test sites selected include the University of Alaska, State of Nevada, New York's Griffiss International Airport, North Dakota Department of Commerce, Texas A&M University - Corpus Christi, and Virginia Polytechnic Institute/State University. Together, the selected test sites provide "geographic and climatic diversity" (para. 3) allowing the FAA to establish the body of evidence necessary, along with a verification mechanism, for developing regulations and operational procedures needed to support future commercial and civil use of the NAS [37].

IV. AVIATION EMERGENCY USE CASE EXAMPLE

An example scenario where the benefit of UAS application can be observed is in response to a commercial airline accident, where the pilot has declared an emergency, airport operations have been halted, and the subject aircraft remains at the end of a runway with a fire and passengers evacuated; a scenario similar to the Asiana Airlines Flight 214. Assuming acceptable environmental conditions that do not limit application (e.g., visual flight rules [VFR], gusting headwinds, crosswind component, and precipitation levels within

operational parameters for given UAS), it may be possible to utilize several UAS to: 1) quickly deploy concurrently with first responder mobilization, 2) establish a sensing perimeter around the aircraft, 3) gather intelligence and details of the emergency and site, and 4) communicate information regarding the situation as it unfolds to emergency management team and responders (i.e., establish, maintain, and communicate an accurate situational awareness model; see Fig. 1) [38], [39].
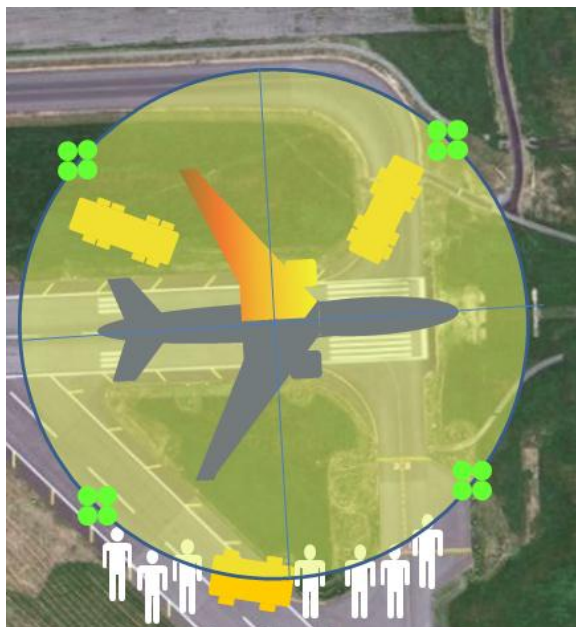

Figure 1. UAS sensing perimeter established around aviation emergency scene with emergency response equipment routed to critical areas.

Creating and maintaining an accurate situational awareness model of the scenario represents an essential component of the previously discussed flexible framework for the capture, processing, and dissemination of information (i.e., significant opportunity to improve the effectiveness of response and reduce the potential for responder injury). The potential applications within a response include performing initial triage analysis while responders are en-route (i.e., identify those in most need of immediate care), accurately routing or re-routing of equipment (e.g., medical personnel to injured and firefighting equipment to specific locations of the aircraft), establishing and maintaining security of site, and adapting to dynamic emergency conditions (e.g., spread of fire, immediate injury, or identification of hazardous materials). While the utility of unmanned aircraft to support public safety emergency response has been established and supported [40][41], more must be known about how this technology can best be incorporated into the existing framework, specifically in relation to ARFF.

V. RECOMMENDATIONS AND CONCLUSIONS

The future of UAS and technology associated with this industry is set to grow exponentially. Currently, over a dozen different types and over 8000 unmanned aircraft

are operational within the military services and other federal government agencies. Additionally, there are many public agencies and private industries that have a need for routine use of UAS technology as well as over 18,000 police departments, fire departments, and other first responders who have expressed interest in this technology, and recognize the potential wide range of beneficial, lifesaving applications within the NAS [42].

The future effect on the NAS will be concerns over safety and overcrowding. Advancements in technology can help to mitigate these concerns to some degree, but reliability on the human component will be a critical issue for many years to come. The general population is only recently becoming aware of the great potential and future capabilities of this technology. In order for UAS to flourish in the future, the general public must be convinced that this technology is safe and reliable.

From a human factors perspective, the future of UAS HMIs depends upon the industry making use of safe, reliable, and intuitive technology that will not only allow the human component to operate these vehicles in a safe manner, but will also optimize human capabilities while mitigating their limitations. Interfaces that utilize adaptive and flexible automation and algorithms, touch screen technology, text messaging, and reliable voice recognition technology will be key factors in future HMI development. Intuitive displays that relay information to the human quickly and efficiently, maintaining high levels of situational awareness, while assisting in decision making along with control interfaces that allow the human to relay control inputs to the system quickly and reliably will be just as important.

Areas for future research include UAS integration into the NAS, autonomy, more intuitive HMI development, aerodynamics and airframe development, training effectiveness, privacy and legislation issues, and development of long duration powerplant operations. Uses of UAS for the civilian sector are numerous and the list is growing daily. The trend in military UAS applications is to replace manned missions that are typically classified as "dull, dirty and dangerous [43]. The terms "dull, dirty and dangerous" not only describe a significant part of warfare activity, but can also be applied to many tasks where UAS technology can be most useful, including but not limited to things such as pipeline monitoring, agricultural and crop-dusting applications, wildfire aerial assessment, and disaster response and relief efforts.

One of the most redeeming features of a UAS used in disaster response and recovery efforts is the ability of the UAS to transmit information from sensors and payloads back to the ground control station (GCS) for processing. The ability of the UASs to fulfill their missions depends in large part upon the communications link between the UAS and the GCS [44]. These two factors allow UAS units (UAS and GCS) to enter an affected area quickly while leaving the human component behind in a safe location to process information and coordinate response and recovery activities. Sending the UAS into the hazardous area to perform the missions related to damage

assessment and search for stranded individuals in need of assistance can be performed much sooner than normally possible if the technology were not present and available. This allows enhanced situational awareness for rescue and response personnel along with pinpoint focusing of resources where needed instead of blanket coverage and inefficient rescue operations.

This type of technology would be ideally suited to assist in situations related to ARFF planning, response, and management. Asiana Flight 214 that crashed at San Francisco in 2013 resulted in three fatalities and 180 of 307 passengers injured (58% injured) [45]. One of the fatalities resulted from a passenger being run over by an emergency response vehicle. If UAS technology were deployed at emergency situations such as these, the capability to provide advance information about aircraft and scene conditions long before emergency responders arrive at the accident scene could result in fewer fatalities, improved triage, more accurate and expedited decision making, and improved and efficient utilization of existing resources. Video and sensor imagery relayed to the first responders could provide information about location of victims, location of fire or other hazards, and equipment needed to manage such situations more safely, efficiently, and effectively.

It is hypothesized that through use of diverse UAS sensing and communication capabilities, flexibility and accuracy of the emergency response can be enhanced, rather than interfered with or obstructed. However, making an accurate determination will require more in-depth analysis. Further research into this topic using tools such as modeling and simulation, mission planning software, and advanced UAS technology demonstrators, coupled with mixed-methods (i.e., qualitative and quantitative) data capture, analysis, interpretation, and reporting may result in an improved understanding of how UAS can best be utilized to improve safety, promote efficiency, and realize effectiveness in aviation emergency response. It is recommended that further research be developed and performed to examine and identify optimal opportunities to incorporate UAS technology as a means to enhance situational awareness, with findings disseminated among stakeholders and potential users.

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