NASA Research to Expand UAS Operations for Disaster Response

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Abstract

Natural disasters can result in the loss of life and cost governments and private industry billions to recover each year. Over the past decade the rate and severity of natural disasters such as wildfires and hurricanes have resulted in increasingly negative impacts to communities, public health, natural ecosystems, and the economy. To help reduce these impacts, NASA's Aeronautics Research Mission Directorate is working to advance technologies and enable the safe and efficient inclusion of novel aviation applications to better assist in disaster response. To execute on these efforts, NASA's Advanced Capabilities for Emergency Response Operations (ACERO) and System-Wide Safety (SWS) projects have developed coordinated strategic research plans focused on aviation operations for disaster response. The ACERO project will be a multi-year effort that focuses on enabling the use of uncrewed aircraft systems (UAS) to improve firefighter safety and efficiency and enable the use of UAS to conduct new missions such as logistics and aerial suppression. The ACERO project will demonstrate technologies that support the Second Shift concept, enabling UAS and ground technologies to support aerial suppression in degraded visual conditions (e.g., heavy smoke, nighttime). The SWS project will be a multi-year effort that focuses on addressing the key safety barriers that are preventing the authorization of UAS operations in a variety of increasingly complex disaster response applications: post-hurricane response, medical courier, and urban disaster response. The SWS project will demonstrate an In-Time Aviation Safety Management System (IASMS) designed to effectively monitor, assess, and mitigate safety risks associated with hazards to UAS operations for disaster response. This paper will provide a deeper insight into NASA's research and development plans and discuss how solutions developed in partnership with industry stakeholders and federal agencies will improve disaster response across the globe.

Keywords: Disaster Response, UAS, Safety, Air Traffic Management, Safety Management

1. Introduction

The prevalence and severity of natural disasters has greatly increased over recent decades due to global warming and climate change. The increased occurrences of tropical storms, earthquakes, tornadoes, and wildfires have produced devastating global impacts to economies, wildlife and vegetation, infrastructure, and resulted in substantial loss of life. In 2018, the National Oceanic and Atmospheric Administration (NOAA) released the Fourth National Climate Change Assessment report that concluded that there had been at least 44 weather and natural disaster events that were over a billion dollars each and the United States had incurred costs of over 400 billion dollars between 2015-2018 [1]. NOAA annually tracks the frequency and costs associated with natural disasters that exceed a billion dollars per event.

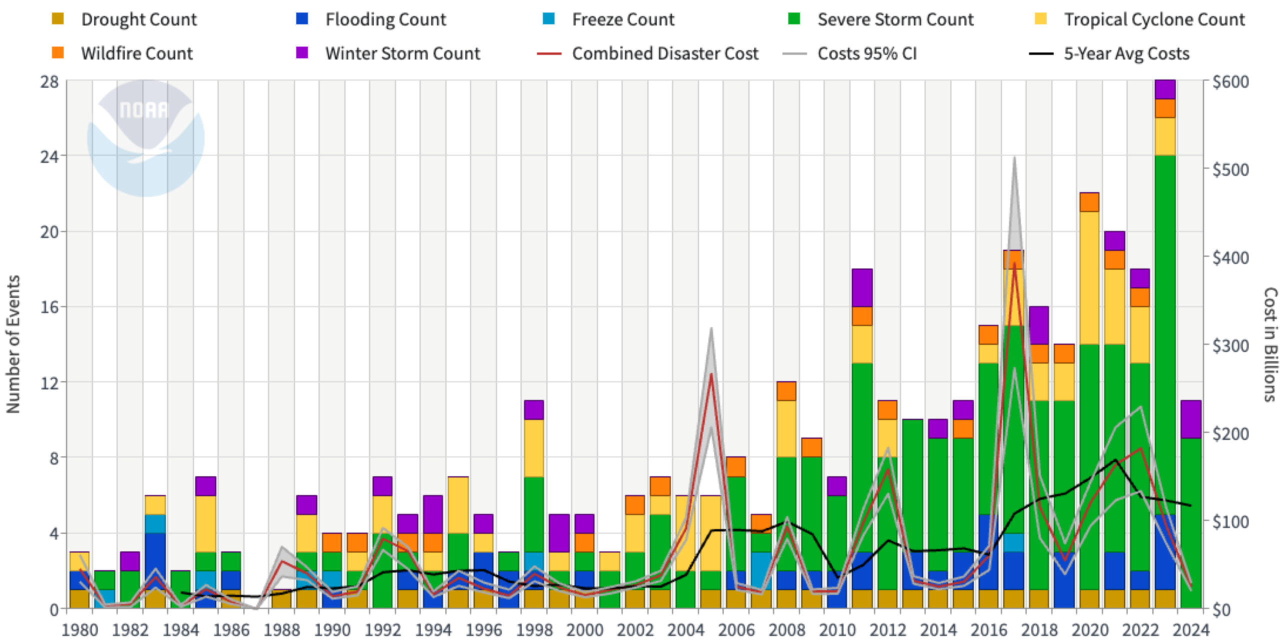

Figure 1- United States billion-dollar disaster events from 1980-2024, as of June 10,2024.

Figure 1 depicts NOAA's assessment, as reported on June 10, 2024, of the billion-dollar events in the United States (US) since 1980 [2]. It is evident that the frequency, severity, and costs of natural disasters has been substantially increasing in the United States. To address this issue, the Disaster Recovery Reform Act of 2018 was signed in October 2018 and directed federal agencies to build the nations readiness for the next catastrophic event. Federal, state, local, and tribal governments have acknowledged that new innovative solutions are necessary to integrate into disaster prevention, mitigation, response, and recovery. For example, weather reports with high accuracy, and frequent predictions and update rates, can be critical for wildland fire response and evacuating communities prior to a hurricane.

Uncrewed aircraft systems (UAS) have drawn much attention due to their affordability, ease of operation, mission versatility, and reduction of risk to emergency responders' health and safety. Collecting aerial imagery has become a common approach to acquiring data with the introduction of UAS into disaster response operations, however UAS can extend to broader applications in disaster management, such as: assessing damage, search and rescue, conducting mapping, and supporting wildfire management (e.g., aerial ignition) [3], [4]. The integration of more modern aviation technologies into disaster response operations will enhance safety for emergency responders, improve effectiveness of the response, and help mitigate the impacts of climate change to support more resilient communities.

While UAS are gaining popularity in their application to disaster management, the integration of UAS into operations is limited by several factors including regulatory restrictions preventing access to airspace and ensuring safety and privacy [5]. Current regulatory processes are insufficient in enabling the safe, rapid deployment of disaster relief operations with novel operational (e.g., increasingly automated or autonomous) paradigms. For aircraft that can employ a standards-oriented approach, certification timelines for conventional aircraft systems often range between 5-7 years. Similarly, operational approvals and access to the airspace require tailored arguments for non-conventional operations. There are limited standards that apply to these operations, and each safety argument must be tailored to the specifics of the disaster operation (e.g., geographic location, season, time-of-day, etc.), thus preventing reuse of safety arguments across similar operations and increasing time-to-deployment.

To enable the safe integration of UAS for disaster response, the NASA Aeronautics Research Mission Directorate (ARMD) is working to advance technologies and enable the safe and efficient inclusion of novel aviation applications to better assist in disaster response. To execute on these efforts, NASA's Advanced Capabilities for Emergency Response Operations (ACERO) and System-Wide Safety (SWS) projects have developed coordinated strategic research plans focused on aviation operations for disaster response.

This paper will provide an overview of these research efforts, discussing safety assurance and risk management considerations for UAS operations, details of envisioned deployment concepts for UAS in Active Wildfire Suppression, and the ongoing research and development efforts to mature and integrate advanced technologies necessary for safe deployment of UAS across a variety of emergency response applications.

2. Safety Assurance and Risk Management for UAS

Unlike traditional aviation with a pilot on-board, UAS are deployed with a substantially different mode of operating that includes a highly integrated suite of sensors and increasingly automated functionality to enable effective flight management by a remote pilot-in-command. With the increase in complexity of integrated and increasingly automated systems, UAS operations introduce several new hazards and related risks to the overall operation and larger airspace system that must be effectively managed. Assuring safe operations and acceptable level of safety for the airspace requires the timely identification and mitigation of emergent safety risks through effective implementation of safety risk management and safety assurance processes. With the envisioned increase in number and variety of UAS operations in the airspace, coupled with other new entrants with novel operational paradigms, the responsiveness of safety risk management and safety assurance processes becomes increasingly important to maintain acceptable levels of safety, even in high-risk tolerant operational paradigms such as disaster response. A report by the National Academies further outlines the safety challenges that must be addressed as the airspace system increases in complexity, describing the need for an “In-Time Aviation Safety Management System” (IASMS). The IASMS is described as a system that “continuously monitors the airspace system, assesses the data that is has collected, and then either recommends or initiates safety assurance actions as necessary. Some elements of such a system would function in real time or close to real time, while other elements would search for risks by examining trends over a time frame of hours, days or even longer.” [6]

NASA has worked closely with industry to generate consensus on desirable system traits of an IASMS that is proactive and predictive in its capacity to monitor, assess, and mitigate risks for existing and new entrants to the airspace system. In 2020, NASA published an initial concept of operations for design consideration and future implementation of an IASMS, describing key stakeholders and a variety of interconnected services, functions, and capabilities (SFCs) designed to monitor and assess system performance across the operational network. The SFC components of an IASMS are designed to work together to analyze and identify elevated risk states to then inform or even execute automated mitigation strategies or safety assurance actions [7].

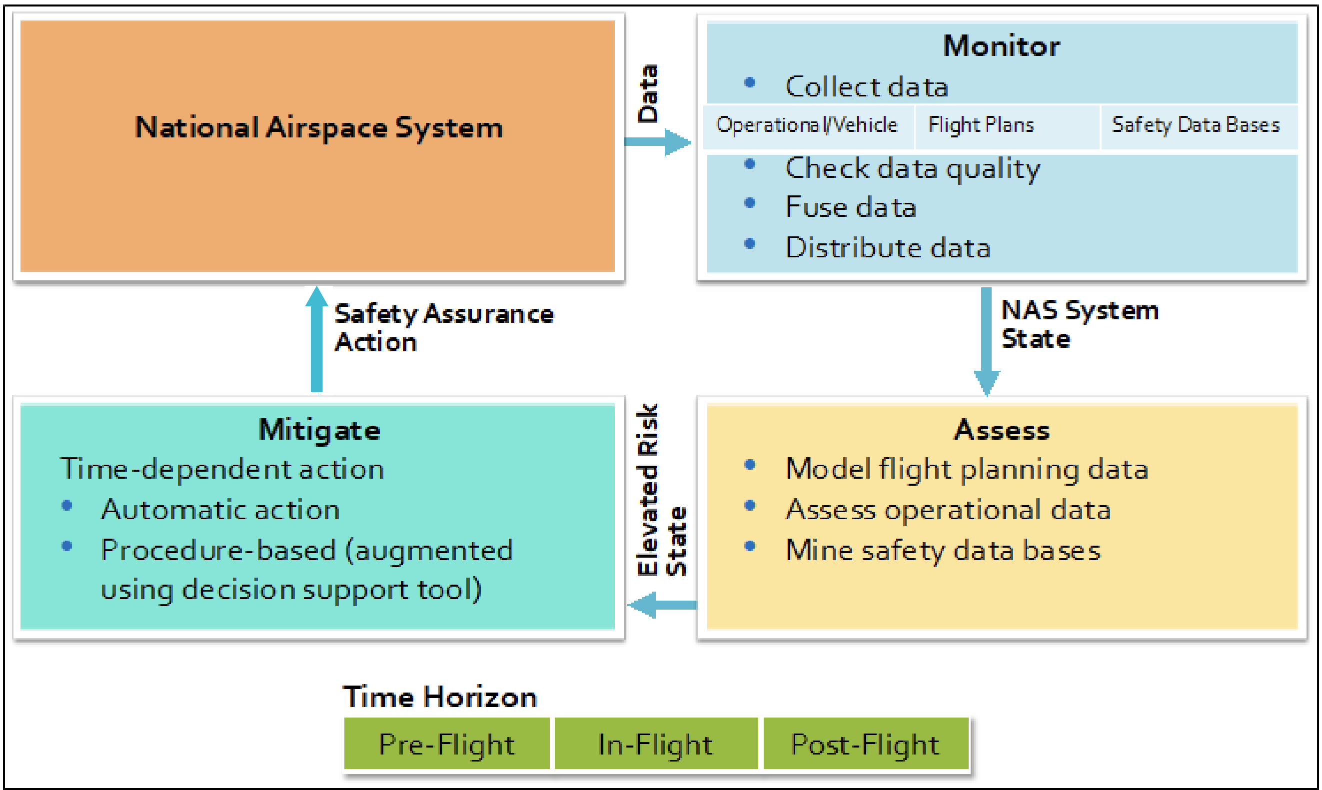

Figure 2 - IASMS High-Level Architecture *[6]*

Safe deployment of UAS for disaster operations will require timely safety assurance strategies, achieved through the implementation of an IASMS capable of proactive and predictive risk mitigation. NASA and others in the aviation industry have identified several safety-critical risks to UAS operations including: flight-outside of approved airspace; unsafe proximity to people or property; critical system failures including loss of link, loss or degraded positioning system performance, loss of power, and engine failure; loss-of-control due to envelope excursion or flight control system failure; and cyber-security related risks introduced with the highly digital architectures often deployed for UAS [8]. Identification of these risks and their contributing factors help to prioritize development of an IASMS for UAS in disaster response operations by providing the context to develop requisite monitor-assess-mitigate capabilities for in-time safety assurance. Additionally, IASMS plays a critical role in better understanding the emergent effects generated by the increased use of automation and autonomous functions, which can introduce new hazards to the operation in unanticipated ways and pose a danger to emergency response personnel or 3rd party individuals [8].

3. UAS Support for Active Fire Airborne Suppression

Fire is a natural disturbance and fundamental process in many ecosystems. Across the United States, however, due to a combination of increased fire season length, human caused climate impacts, and an expanding area where wildland vegetation and communities intersect, wildland fires have become more frequent and have increased the amount of acreage burned every year. This can lead to increasingly negative impacts on communities, public health, the economy, and ecosystems. Natural disasters, like wildfires, can lead to loss of life, damage to property and infrastructure, may have long-term effects on human well-being, and costs the U.S. billions of dollars each year. Wildland fires have a detrimental connection to climate change through the creation of conditions that yield a greater availability of fuel and an increase in natural and human-caused ignition sources which is resulting in fires that are bigger, more severe, that move faster than before, and ultimately are more destructive. While the impact of climate change on wildland fires is well established, wildland fires conversely can have significant effects on the climate, associated ecosystems, air and water quality, and short-term and long-term human health and wellness.

Initiated in 2023, the ACERO project is a multi-year research effort that aims to develop, demonstrate, and transition to operations, advanced aviation technologies, (such as UAS, automation, and UAS traffic management [9]) to identify, monitor, and suppress wildland fires. Current wildfire operations leverage a wide variety of aircraft that might be involved in an aerial attack of a wildfire: tankers releasing fire retardant, lead planes to guide them, helicopters dropping off field crews, aircraft from which smokejumpers arrive on the scene, UAS providing aerial ignition, etc. Responding to large scale wildfires requires extensive collaboration among a large group of stakeholders that, right now, is coordinated manually under challenging conditions. Furthermore, effective decision-making in wildfire operations can also be challenging due to a lack of timely information and the overabundance of data that is presented to the decision-makers. The ACERO project will focus on four main areas of research: leading the development of a multi-agency concept of operations for wildland fire management [10], improving communication and coordination for aerial firefighting operations through the integration of a digital traffic management ecosystem, extending the ability for firefighters to conduct aerial operations during low visibility conditions and night operations using drones for remote sensing, communications, and suppression, and enhancing the safety of existing aerial operations and supporting the increased use of drones by incorporating aircraft safety automation systems.

The ACERO project is collaborating with other NASA science and space technology development projects, federal and state wildland firefighting agencies, and commercial industry to conduct field demonstrations through the preventative, active response, and post disaster recovery phases of wildland fire management operations. ACERO will leverage public-private-philanthropic partnerships to accelerate commercial availability of the technology developed and tested to support wildland fire operations.

3.1 Wildland Fire Management “Second Shift” Concept

NASA conducted a series of workshops, tabletops, and interviews with federal, state, tribal, and local agencies from the wildland fire management community to better understand the current state-of-the-art, the future challenges and needs, and the opportunities for advancements in science and technology to improve wildland fire management response. Through this engagement several community needs were identified as [11], [12], [13]:

- Interoperable and reliable solutions for wildland fire detection, monitoring, and tracking,
- Interoperable and resilient communications architecture and solutions,
- Persistent aerial suppression operations particularly under poor visibility,
- Airspace technologies to enable multiple types of aircraft operating simultaneously, and
- Improved coordination among multiple government agencies.

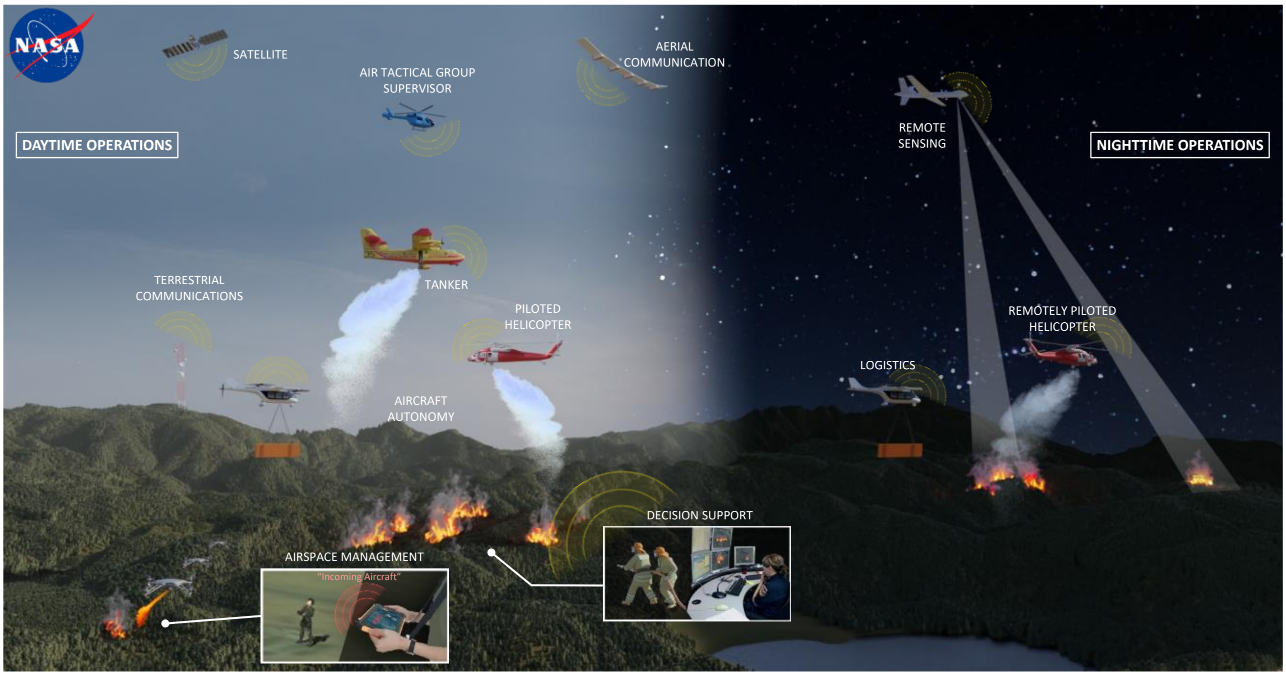

Figure 3 - Remotely piloted suppression and logistics operations in degraded visual environments.

The ACERO project is focused on advancing UAS technologies, air traffic management technologies, communication technologies, and autonomy to expand aerial suppression operations into degraded visual environments, where current operations aren't conducted today. The goal for expanded aerial suppression operations is to enable sustained, 24-hour aerial firefighting to reduce the intensity and spread of a wildland fire, providing support to ground crews to contain the fire. One key barrier to enabling sustained aerial firefighting is the inability to carry out aviation operations in degraded visual environments (DVEs). Darkness, smoke, haze, and other visually impairing meteorological conditions often limit aerial operations to 6-8 hours per day. These current limitations are due to the loss of situation awareness, and an elevated risk of collision, when operating in DVEs. Another key barrier is the fact that wildland fires often occur in remote, rugged areas with little or no means of reliable communication. The lack of reliable, consistent connectivity prevents the wildland fire community from achieving a common operating picture (COP) that provides timely information. For the purposes of this paper, the concept of using remotely piloted operations and ground technologies to support suppression and logistics missions in degraded visual environments is called Second Shift. This Second Shift concept, as shown in Figure 3, would allow for aviation technologies, like UTM, to support crewed suppression operations during the day (i.e., First Shift), and when visibility degrades remotely piloted suppression and logistics operations can continue without imposing an unnecessary risk to pilots.

The ACERO Project is collaborating with other programs in NASA's science and space technology mission directorates, and other federal and state wildland fire management agencies to develop a concept of operations (CONOPS) for the future integration of technology into wildland firefighting. This CONOPS includes the second shift concept along with other concepts that integrate technology into wildland fire operations.

3.2 ACERO Technical Capability Level (TCL) Operational Evaluations

The ACERO project will collaborate with other agencies and industry to demonstrate technology through field testing. These demonstrations will support the following wildland fire operation use cases that contribute to the Second Shift concept:

- **Monitoring** – The persistent collection, processing, and dissemination of remote sensing information to inform timely decision-making for 24-hour aerial firefighting operations.
- **Communications** – The interoperable satellite, mobile, terrestrial, and aerial communication networks that provide reliable communication and connectivity to support airborne and ground operations for 24-hour aerial firefighting operations.
- **Logistics** – The use of remotely piloted aircraft, autonomy, and supporting technology that enable cargo and supply delivery to and around a wildland fire incident.
- **Suppression** – The use of remotely-piloted and/or optionally-piloted aircraft, autonomy, and supporting models and technologies that are necessary to conduct mission planning, provide a precision drop, verify water/retardant drop effectiveness, tactically re-task more precision drops, and reload water and/or suppressant.

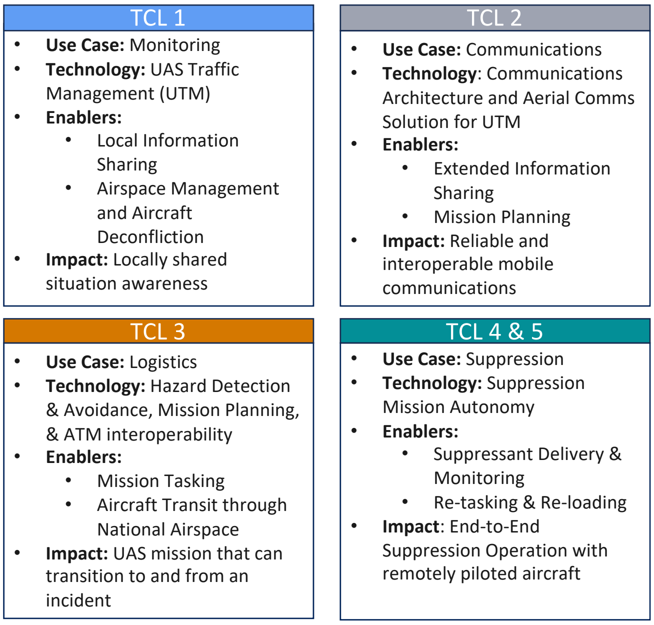

Figure 4 - Progression of the ACERO technical capability level (TCL) operational evaluations.

The ACERO project will conduct annual collaborative technology capability level demonstrations to test the buildup of the technologies needed for second shift. The use cases will be leveraged to exercise each demonstration, where each year the technology will be tested against a different use case from monitoring to suppression, and each use case will build on the prior year's use cases, as illustrated in Figure 4.

4. Safety Demonstrator Series

Initiated in 2018, the System-Wide Safety (SWS) project is a collection of ongoing research efforts to develop, mature, and demonstrate advanced safety technologies to safely integrate new operations into the global airspace, including novel operational paradigms such as Advanced Air Mobility and UAS for disaster response. The scope of the SWS project is to explore, discover and understand the impact on safety from growing complexity of operations, introduced through modernization and technology advancement aimed at improving the efficiency of flight, the access to airspace, and/or the expansion of services provided by air vehicles. The SWS project goal is to develop and demonstrate innovative safety solutions that enable aviation transformation. To that end, the SWS project is responsible for the research and development of both design assurance and operational safety technologies that together contribute to the development of IASMS. The SWS project has worked closely with industry partners and community stakeholders to develop a strategy to mature safety technologies (i.e., SFCs) for integration into a functional IASMS architecture and test it in a series of operational evaluations named the Safety Demonstrator Series.

The Safety Demonstrator Series is comprised of a sequence of increasingly challenging disaster response operational domains with specific contextual use cases, shown below in Figure 5 - Safety Demonstrator Series Use Case Progression The design space for the Safety Demonstrator Series has multiple dimensions that must be considered simultaneously. Key dimensional factors identified for evaluating the problem space are: risk tolerance, complexity, and uncertainty. Risk tolerance primarily affects the design assurance level of the IASMS and each component SFC, while complexity and uncertainty primarily affect the number of SFCs needed to address the number of hazards associated with those operational dimensions and be integrated into an IASMS capable of in-time safety management. To demonstrate the feasibility and potential of the enabling capability concepts, the specific use cases will be selected based on where the greatest potential for positive impact resides with respect to enabling future operations and the availability of test vehicles, supporting facilities, and partnerships with relevant stakeholders.

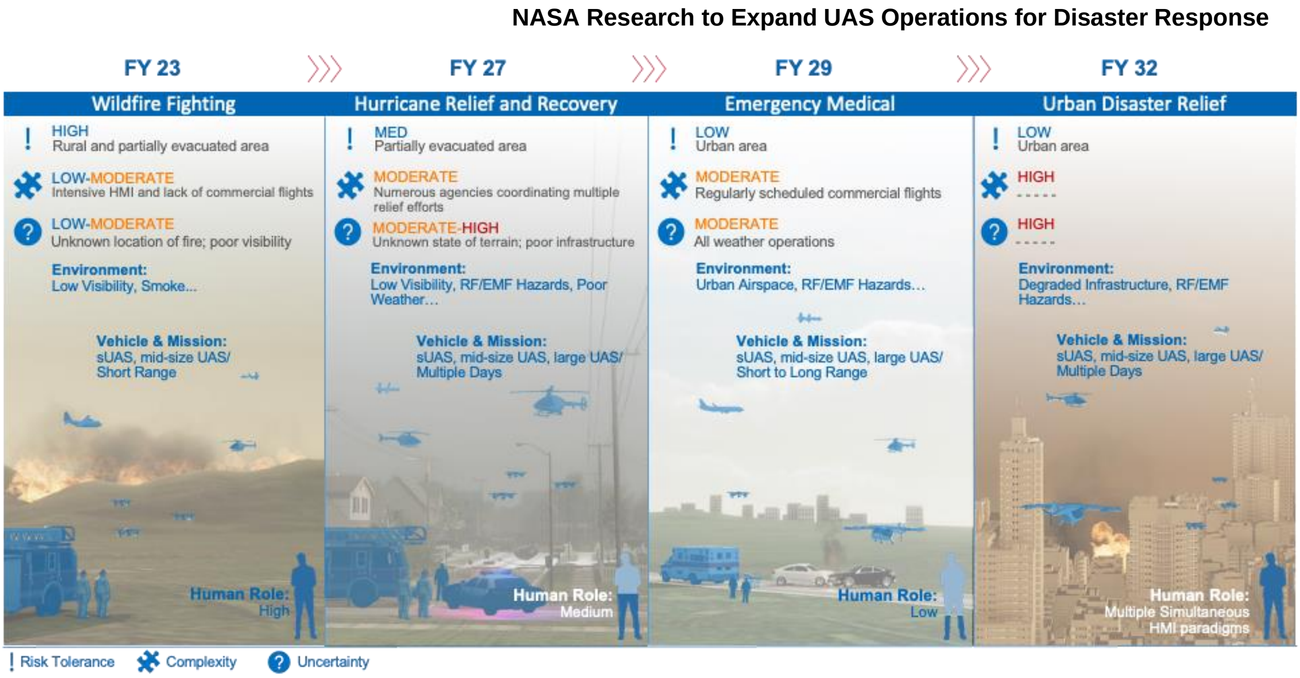

Figure 5 - Safety Demonstrator Series Use Case Progression.

As the progression of domains and use cases occurs, an iterative approach to research, development, test, and evaluation will be employed to refine previously developed safety services, functions, and capabilities (SFCs) that will define the domain-specific IASMS. Each use case will have a defined concept of operations and is expected to have a tailored list of hazards identified through formal hazard analysis, some of which may be held in common across multiple use cases, thereby allowing for the maturation of the specific SFCs that act to mitigate that hazard. As shown in Figure 6, as the risk tolerance, severity, and likelihood of a common hazard changes across use cases, the assurance level of the mitigating SFCs will need to change as well. Both the assurance (i.e., design reliability) and maturity (i.e., alert, automated, autonomous functionality) levels of given SFCs will increase as the Safety Demonstrator Series progresses. A critical element of this research is to rapidly identify, model, demonstrate, and assure means of mitigating both design and operational safety-critical risks in a complex system operating in an uncertain environment.

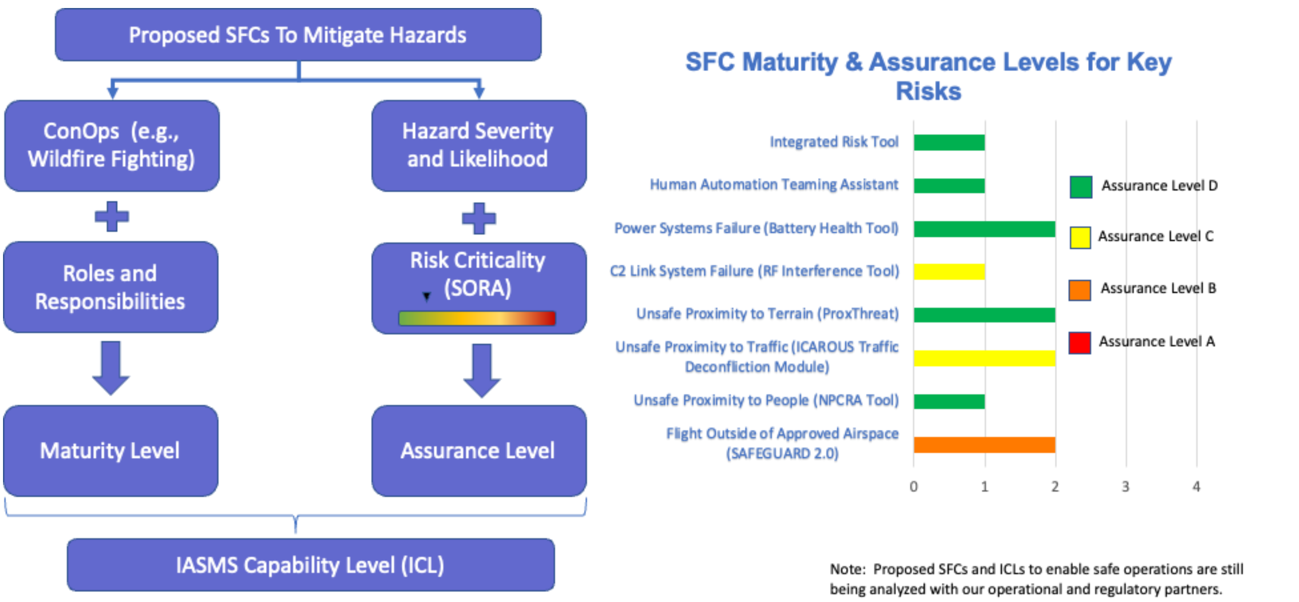

Figure 6 - Criteria to Identify Specific SFC with Requisite Assurance and Maturity Level for Effective IASMS Capability.

The SWS project works closely with industry stakeholders interested in supporting each use case, as well as the local regulatory authority to determine acceptable means of establishing safety assurance for operational approval. This process outlines the requirements for which SFCs to be integrated into an IASMS framework to effectively address the safety critical risks and hazards identified for the proposed use case. Once the functional and assured IASMS implementation is developed, SWS will operationally evaluate the IASMS in the context of the use case and determine the efficacy of the IASMS implementation to assure safety and effectively manage risks. The data generated by each use case can then be used to inform recommendations for a variety of related system standards and approval processes. SWS works closely with several standards development organizations such as SAE, RTCA, EUROCAE, UL, and ASTM as key stakeholders to our technology transfer strategy. Figure 7 below shows the general IASMS development and technology transfer strategy for each use case.

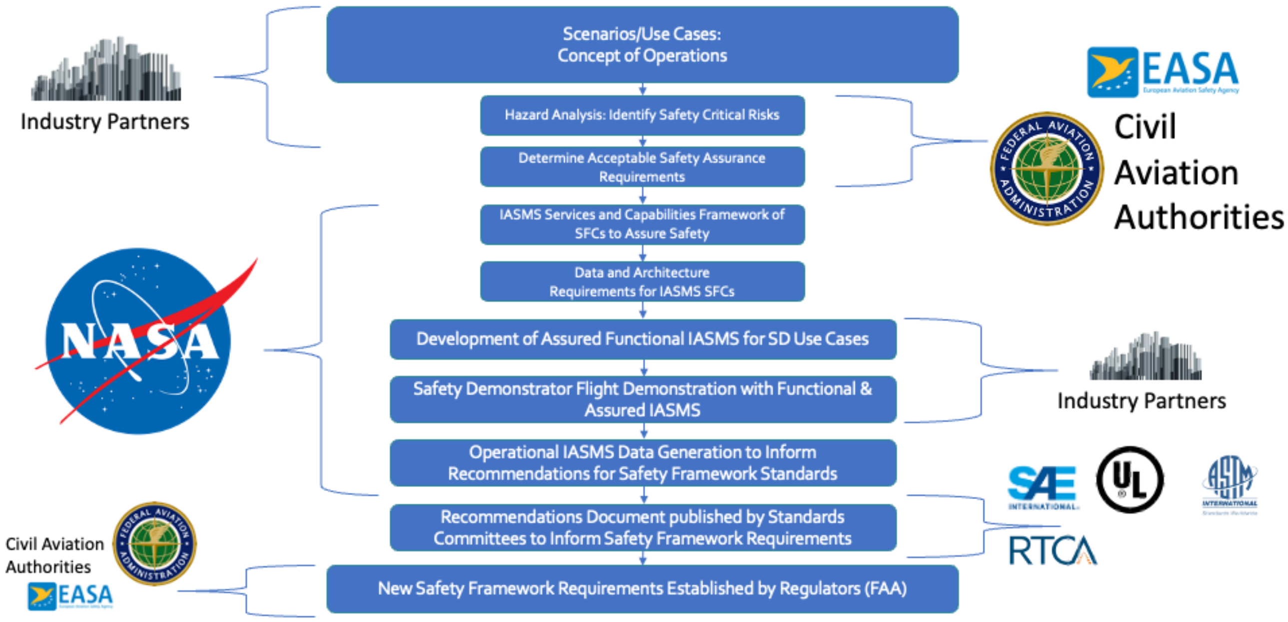

Figure 7 - Safety Demonstrator Series IASMS Development Strategy. [14]

In 2024 the SWS project transitioned from its initial operational domain of wildfire fighting, transferring safety research findings to the ACERO project. SWS is currently focused on developing the concept of operations for the Hurricane Response and Recovery operational domain, coordinating with industry stakeholders and other federal agencies such as FEMA and NOAA to define specific community needs in this emergency response domain which will define specific use cases to build and test reference IASMS implementations. Several UAS applications to assist in hurricane response and recovery operations were identified, including search and rescue, evacuation route assessment, flood damage estimation, and surveillance of coastal regions of interest. Each of these specific use cases within the hurricane response and recovery elicit a variety of operational hazards when deploying UAS, providing a rich context to test and evaluate the efficacy of an IASMS to effectively assure safe operations. Figure 8 presents an operational view with specific hazards and risks identified, with requisite SFCs that will be integrated into the IASMS safety framework.

Figure 8 - Hurricane Response and Recovery Operational View.

5. Concluding Remarks

The societal and economic impact of natural disasters continue to challenge quality of life for all humankind across the globe. UAS present a cost effective and highly capable asset to augment disaster response operations by dramatically improving situation awareness, introducing new means to manage disasters, and remove humans from hazardous activities. While the opportunity of UAS to do public good is well documented, there remain several technical and regulatory barriers to enable the safe and efficient integration of UAS for disaster operations and see that opportunity realized. NASA's Advanced Capabilities for Emergency Response Operations and System-Wide Safety projects are working together with industry, government, and community stakeholders to strategically address these challenges. Operational demonstrations of UAS for emergency response and the novel technologies fielded by both projects and their partners will generate valuable data that can be used by industry operators, standards development organizations and regulators. This data is particularly valuable when determining validated and acceptable approaches to air traffic and risk management, and informing the rules and regulations that govern novel aviation applications. This research serves to advance the integration of UAS into the airspace by demonstrating reference technology implementations and inform future standards-based approaches, thereby enabling the scalable, safe, and efficient deployment of UAS for disaster response operations and unlocking the future vision of aviation's expanded economic and societal benefit for all.

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6. Copyright Statement

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