ENHANCING PUBLIC GOOD MISSIONS AND DISASTER RESPONSE WITH ADVANCED AERIAL TECHNOLOGY: OPPORTUNITIES AND CHALLENGES

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Abstract

In 2023, the International Forum for Aviation Research (IFAR) submitted their ‘Scientific Assessment for Urban Air Mobility’ to the International Civil Aviation Organization (ICAO) Council 2023. This independent scientific statement from 27 of the world’s leading aeronautical research institutions highlighted the potential and challenges for advanced air mobility (AAM). As the researchers worked on this assessment, they identified many commonalities in the original applications expected for new vehicles, i.e., public good missions. This triggered discussions on ongoing research and gaps which need to be bridged so that aviation technologies can aid public good operations such as disaster response and medical deliveries of goods and personnel, for example. This presentation will identify commonalities and differences in the disaster-response research conducted by various IFAR members and discuss major research challenges and remaining gaps. Most common use cases and types of disasters are shown and analyzed. Special attention is given to advanced air mobility applications, integration of crewed and uncrewed vehicles, automation and new sensors and data analysis which can benefit fast and efficient disaster response.

Keywords: disaster response, mission, airspace integration, uncrewed aircraft systems (UAS), drone, advanced air mobility (AAM)

1. Introduction

1.1 Public good and disaster response

Novel aircraft such as uncrewed aircraft systems (UAS) and electric vertical takeoff and landing aircraft (eVTOL) are envisioned to improve connectivity and easy transportation of good and services. In 2023, the International Forum for Aviation Research (IFAR) submitted their ‘Scientific Assessment for Urban Air Mobility’ [1] to the International Civil Aviation Organization (ICAO) Council [2]. This independent scientific statement from 27 of the world’s leading aeronautical research institutions highlighted the potential and challenges for advanced air mobility (AAM). While the scientific assessment was focused on urban air mobility, many of the discussions and preliminary work identified commonalities in expected early operations of both UAS and AAM: point-to-point transport of goods and passengers, and public good operations [3]. Public good missions benefit the community, or society as a whole, contributing to equality and enhanced public welfare. Public good missions provide non-excludable and non-rivalrous benefits, and they are available to everyone who needs them. Such missions are aimed to serve the common good rather than generate profit. Disaster response can be considered a public good, as they provide non-excludable and non-rivalrous widespread benefits to the affected population. More rigorous definitions of public good and a public service can be found in National Aeronautics and Space Administration (NASA) report on AAM missions for public good [4]. In regard to public good new entrant aviation operations, two major types of operations can be identified: novel aircraft substituting traditional vehicles in existing operations and new missions made possible thanks to the extended capabilities offered by new entrants. Transport of injured people, necessary medical equipment and supplies have been shown to receive high public acceptance as well. In ASSURED-UAM [5] project public good operations were included within "public service" category of UAS operations. They covered both daily (often planned) priority operations like blood, medicine transportation as well as on-demand flights dedicated to provide necessary support e.g. life-saving items to various accident or disaster sides (one of considered types of mission stipulated landing in unprepared, public spaces to deliver AED). The European project AiRMOUR [6], coordinated by VTT Technical Research Centre of Finland, researched novel AAM concepts in Finland, other countries, and the United Arab Emirates. The EMS were recognised as one of the most anticipated categories of services to supplement the existing Helicopter Emergency Medical Service (HEMS) operations and the other EMS and Emergency Response (ER) services. Four scenarios were identified and validated in the course of the research. The first scenario is the UAS-based transportation of medical products and laboratory tests. The other scenario is the UAS-based delivery of medical products and relief items to the ad-hoc location. One additional scenario is the eVTOL-based transportation of people interfacility or a patient to the hospital or emergency care. The final scenario is the eVTOL-based transportation of medical professionals to the ad-hoc location. Drones aiding immediate post-disaster reconnaissance and search, as well as assisting in fire response have been considered as valuable additions to the aircraft fleet. Routine medical deliveries of tissue samples, urgent organ transplant and blood products are some of the time-critical uses cases where drones can be a solution. Drones can be used in both routine and disaster response operations for ground infrastructure inspections, including overall road quality inspections, obstruction check due to fallen trees after a storm, and detection of seasonal impact such as snow/ice coverage in winter. Public good mission examples also include border protection, coast guard and traffic surveillance as well.

1.2 Climate change and increased number of disasters

A disaster is "a serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources" [7], which can be caused by various types of hazards, natural (e.g., earthquakes, floods) or man-made (e.g., armed conflicts, industrial accidents). Climate changes towards warmer and more unpredictable weather, increased frequency and severity of extreme weather phenomena such as heavy rain and drought have contributed to more wildfires and floods. Natural disasters have increased in numbers, severity and versatility, putting pressure on disaster management personnel and resources. According to the 2020 Ecological Threat Register (ETR), there has been a tenfold increase in the number of natural disasters worldwide since the 1960s [8], [9]. Floods and storms accounted for 71% of the natural disasters between 1990 and 2019. While wildfires accounted for 3.4% of all natural disasters worldwide, in some regions their frequency and severity have been significantly higher than the global average. In Australia and the United States, for example, wildfires constitute of 19% and 12%, respectively, of all natural disasters [9]. The occurrence of severe wildfire events is related to very high and extreme wildfire danger conditions under climate change, with more than half a million hectares being burnt in Europe in 2023 alone [10]. With this negative trend expected to continue, the need for new technologies in disaster management is apparent. Therefore, in Poland, for example, research focus is set on development of UAS supporting firefighting activities and searching and detecting of people on wide areas.

1.3 A note on terminology

The Urban Air Mobility (UAM) concept is focused on, but not limited to, rules, procedures, and technologies that enable the movement of cargo and passenger aircraft in the urban environment, using innovative aircraft configurations (e.g., eVTOLs). In the United States, the Federal Aviation Administration (FAA) and NASA have defined a broader term, Advanced Air Mobility (AAM) [11], which includes a broad set of vehicles, innovative technologies, and covers urban, regional, and interregional operations. In the European project AiRMOUR, however, AAM is defined as “an air transportation system that moves people and cargo between places previously not served or underserved by aviation – local, regional, intraregional, urban – leveraging new technologies and possibilities, where some of these are still under development” [12], thus encompassing small drone operations as well. In Japan, the AAM Concept of Operations explicitly states that AAM does not include drones, and distinguishes further between AAM operations in urban areas over short distances and at low altitudes which is referred to as Urban Air Mobility (UAM), and AAM operations over longer distances which is referred to as Regional Air Mobility (RAM) [13]. In Brazil, the National Civil Aviation Agency published the document "Advanced Air Mobility - Panorama and Perspectives" in 2023, which mostly focuses on eVTOL operations [14]. In the ICAO context, AAM refers to unmanned aircraft systems (UAS), electric vertical take-off and landing (eVTOL) aircraft, and systems supporting operations such as UAS traffic management (UTM) [15]. There are, however, no officially agreed upon definitions and scope of operations covered by both terms, as highlighted in a report by the European Union Aviation Safety Agency (EASA) [16]. Furthermore, the line between unmanned aircraft system (UAS) traffic management (UTM) operations and AAM operations predicted to use U-SPACE [17] also blurry and needs further discussion in the research community. For the purposes of this paper, we consider UAS such as small drones, not capable of carrying passengers; and other advanced aerial systems, such as eVTOL, which are based on passenger or large cargo aircraft. In this paper we will refer to the latter as AAM aircraft.

1.4 Differentiation between ad-hoc and scheduled/ routine missions

Disaster response missions cannot be planned for in advance, as the time, place and scale of disaster cannot be predicted. On the other hand, medical deliveries between two hospitals or medical centers follow an established route, even though the temporal element remains difficult to predict. In this paper, the former are called “ad-hoc operations”, and the latter are referred to as “routine” missions.

From an operation management and airspace design perspectives, such mission characteristics play an important role. Routine operations are more predictable, which allows for detailed airspace and schedule optimization. Airliners trajectories are constructed using well-established air routes, for example, so the air traffic management strategies can be designed to minimize sector workload, optimize throughput and achieve high efficiency while maintaining safety. Ad-hoc operations, on the other hand, are significantly more complex, and often require flexible airspace management and real-time trajectory adjustments. Ad-hoc operations can also disrupt the optimized use of airspace for routine missions, and thus require robust management. The flexibility and real-time adjustments essential for the safe execution of ad-hoc missions requires higher degree of coordination among multiple stakeholders, which can be particularly challenging as such missions are often time-critical. The above mission characteristics and requirements call for a distinction between ad-hoc and routine missions. When the already demanding ad-hoc mission profiles are combined with the exploitation of new entrants, such as UAS, these add yet another layer of complexity to the integration challenges.

1.5 New entrants’ applicability to public good and disaster response missions

The management of a disaster includes all actions taken before, during and after the disruption in order to prevent its occurrence, mitigate its impact and recover from its losses [18]. A typical disaster management cycle will include the following stages: mitigation, preparedness (both in the pre-disaster phase), response (active disaster and immediate aftermath) and recovery (post-disaster). UAS can be used during all phases. There are several case studies addressing the use of UAS for the pre-disaster stages of mitigation and preparedness [19], [20]. Daily operations of UAS can be extended with disaster detecting functionalities allowing for early identification of potentially dangerous or catastrophic phenomena limiting the scale of a potential disaster. Perhaps the most obvious application of UAS is in response and recovery. UAS are very suitable for dirty, dull and dangerous (3D) missions, as they can significantly reduce human exposure to unsafe environment [21] and provide valuable data using remote sensing technologies to help responders evaluate the disaster scale, detect people in need, detect dangerous areas e.g., wildfire hotspots and help to identify safe evacuation or access paths. In fact, UAS offer several advantages that can largely contribute to enhancing the effectiveness, efficiency and safety of disaster response efforts. Besides the ability of reaching locations that otherwise would be inaccessible or dangerous (e.g., radiation environments) for manned aircraft and ground personnel, protecting these human lives, and helping personnel maintain safer distances with extended range of UAS, they can be more quickly deployed to provide immediate aerial surveillance, facilitating the assessment of the disaster scale and reducing the response time for resource allocation. In particular, the rapid deployment of high endurance fixed-wing UAS enable long-duration missions of aerial surveillance, allowing for continuous monitoring of affected areas and sustained search and rescue efforts, for example. UAS can also be deployed in fleets to execute coordinated missions, while being equipped with various types of sensors (e.g., thermal imaging, LiDAR). This is crucial for covering larger areas simultaneously and collecting real-time data to provide comprehensive situational awareness to response teams. Multiple UAS are easier to deploy and they can maintain operational tempo at scale relative to traditional crewed aircraft. Finally, compared to traditional manned aviation operations, UAS typically have lower operational costs and generate lower noise and environmental impacts, representing a more cost-effective and sustainable solution of aerial means deployment for disaster response. UAS can be used in fire suppression and extinction, complementing the work of personnel and crewed aircraft and ground vehicles. UAS can be used as information carrier as well as independent communication interface enabling exchange of information between rescuers and people in need (lacking access to other forms of communication). During and in the immediate aftermath of a disaster, UAS can be used to deliver medical and essential supplies, such as water, communication devices, life rafts (during floods) and other items prolongating survivability of people in needs. UAS are used to provide emergency services and public assistance immediately after the strike of the disaster [22]. In the recovery phase, in particular, UAS are used in risk assessment and insurance claim response.

In addition to small UAS and larger aircraft in AAM such as eVTOLs, High Altitude Platform Systems (HAPS), including High Altitude Long Endurance (HALE) platforms, have proven applications and benefits to disaster response operations [23], [24]. HAPS can take the form of balloons, airships, or solar powered fixed wing, but a common characteristic across platforms is that they operate in the stratosphere and typically stay aloft for days, weeks, and even months. These platforms are also configurable to carry payloads that enable them to monitor wide areas for long durations as well as provide communication relays and connectivity to personnel and systems on the ground. HAPS provide valuable capabilities to fill gaps in remote sensing and communication needs in support of disaster response operations.

2. UAS Applications

2.3 Current operations

A list of drone-based public good applications was compiled based on a collected database of 930 current or prospective use cases compiled from both scientific publications and news feeds or press release articles. Out of the database, 88 use cases were deemed to fit into the public good category. As the use cases contained both very general and overly specific examples, the list was processed into a set of main and sub-categories. The proposed categorization is shown in Figure 1. Note that the classification is focused on disaster ad-hoc missions and does not necessarily include some routine missions such as delivery of medical supplies and safety/security reconnaissance missions, for example. A lot of the routine missions are applicable in the event of a disaster as well, with some modifications in the operations required.

As one of the most earthquake-prone countries in the world, Japan has seen UAS applications to immediate post-disaster responses for several years already. Some of the most recent examples of UAS usage for public good is the Noto Peninsula Earthquake disaster response. The earthquake with a magnitude of 7.6 struck on January 1, 2024, and affected areas in multiple prefectures in Japan. The Japan UAS Industrial Development Association (JUIDA) coordinated with local governments and dispatched drones to conduct post-immediate disaster reconnaissance, search for affected people, medical supplies deliveries, aerial photography and monitoring sediment dams using drone ports over an extended period [25], [26], as well as communications. This disaster response was the first one in Japan where UAS were given special permits to fly within the established no-fly zone dedicated to crewed aircraft. Aerial image has been used to assess landslides and damages caused by earthquakes as well, as in the case of the Kumamoto Earthquake in 2016 [27].

The fire department in Japan has reported continuous and increasing use of UAS for aerial mapping, fire inspection of buildings and forest areas, as well as search for people in distress [28]. Overall, about 50% more departments operated UAS in 2021 compared to 2017.

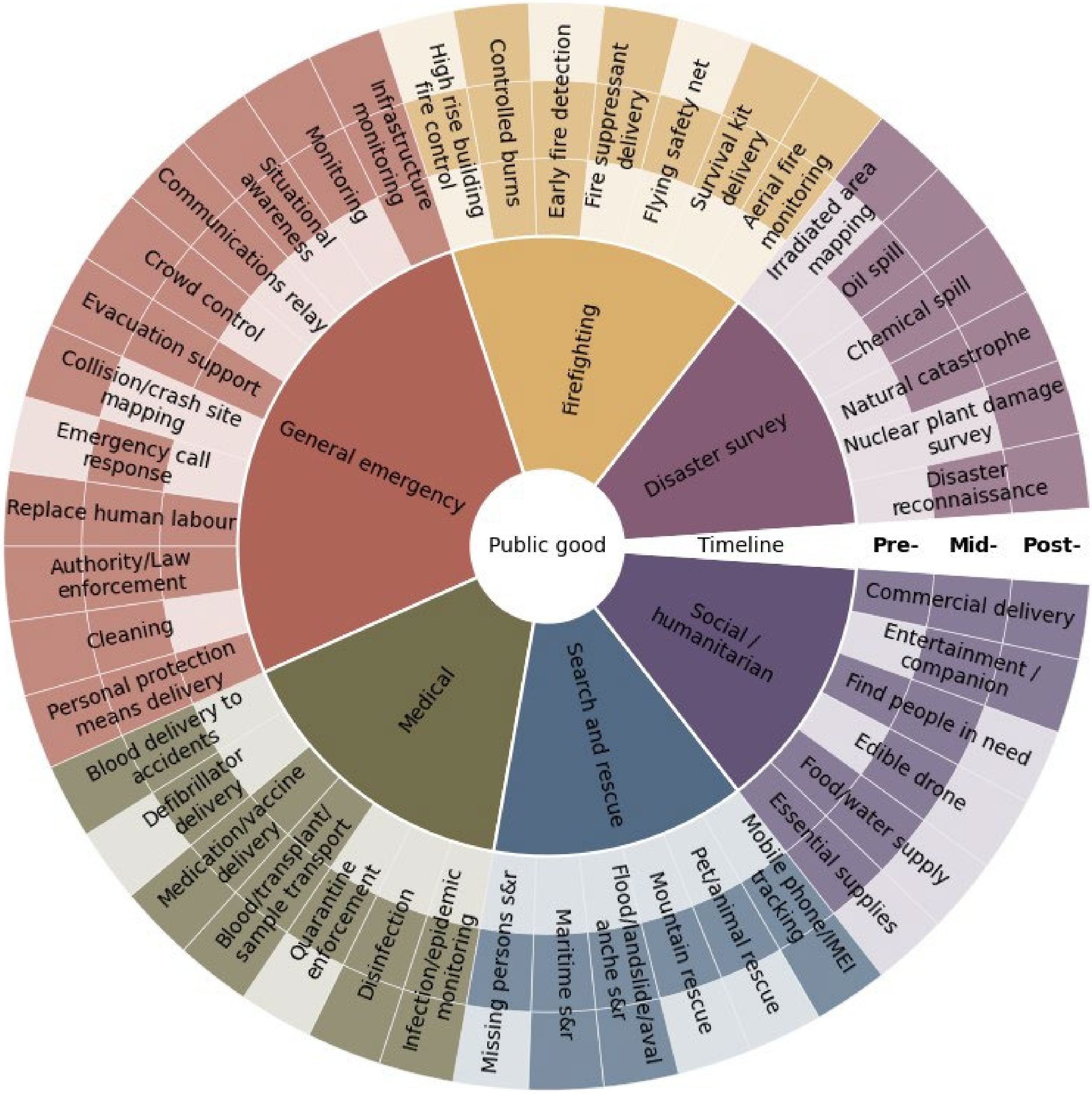

Figure 1 - UAS public good applications.

In Hungary there has been strong theoretical research on the applicability of UAS for firefighting use, such as the work of Bodnar et al. [29]. During the COVID-19 pandemic, the potential use of UAS for various tasks including disinfecting was also investigated [30]. While the theoretical basis was demonstrated, there has been very little activity regarding applying the results in practice. Today drone technology is being intensively adopted by the defense forces and police (including special forces, border guards, immigration, revenue services, etc.), but mostly due to regulatory reasons, there is little uptake by firefighters, disaster response services or EMS. Regulatory challenges are discussed later in this paper.

In Brazil, the area of public safety and/or civil security accounts for the fourth highest number of drone registrations for professional use, according to data from the National Civil Aviation Agency (ANAC). Drones have been extensively employed by the Armed Forces, Fire Departments and Civil Security offices to help in the search and rescue and identify areas/constructions in risk of collapse during the largest disasters in the country, such as the Brumadinho dam disaster in 2019, the Petrópolis landslides and flooding in 2022 and, more recently (May 2024), the massive unprecedented flooding of the Rio Grande do Sul state. Towards mitigation and preparedness, Civil Security offices have been using drones alongside satellite imagery analysis to monitor hillside areas that are prone to landslides, focusing on vegetation coverage and signs of terrain instability [31]. Public security agents and local communities have also used drones to improve surveillance capabilities and emergency response during fire outbreaks in the Amazon region [32].

In the context of disaster related applications in Poland, UAS have several key applications. First, they have been used for regular transport of medical samples between two locations (Warsaw and Gdansk). The operations are automatic and beyond visual line of sight [33]. Another use case is the search for people in distress or individuals wanted by the police. The last key UAS application is situational assessment during wildfires and disasters in urban environment. In these cases, operations are executed in restricted airspace beyond visual line of sight, depending on the need. In Poland due to geographical location the most relevant risks are found to be imposed by flash floods, i.e., heavy downpour caused severe flooding; wildfires; and more and more common droughts. Moreover, the Tatra Mountain range located in southern Poland greatly justifies daily SAR operations. Therefore, the research is oriented on development of AAM- based tools for better situational awareness during wildfires, detecting people in various environments as well as remote sensing to help with the plant health-assessment, specifically in agriculture.

In Germany, crisis management and disaster response are becoming more important in recent years. The rural area of Ahrweiler, having become well known as the Ahrtal disaster, experienced a disastrous flooding event in 2021 after persistent heavy rainfall, with more than 180 fatalities and expected recovery costs of 30 billion Euro [34]. While the public and disaster response units were quickly helping and supporting, it also became evident that the collaboration of units is lacking, even leading to difficulties and danger in the operations. Drone crews were trying to capture images and videos to assess the situation, while manned helicopters were also used for various relief and operational picture support. As there was no common operational picture available, this unknown situation in the lower altitudes posed threats to the operations.

In the United States, UAS have been increasingly used in support of public safety and disaster response across a variety of use cases. In public safety, Drone as First Responder (DFR) programs are proliferating among agencies throughout the country. In DFR, UAS are quickly deployed to the scene of an incident (e.g., fire or reported community danger) allowing for quick assessment of the situation and ability to plan a response without exposing personnel to undue risk. UAS have also been used for search and rescue support for many years. In disaster response, following devastating hurricanes, UAS have been used to assess damage, identify hazards, locate persons in need of rescue or supplies, etc. UAS have also been used in support of wildland fire response efforts to provide situation awareness of fire activity from detection to active tracking and prediction. An additional application has been aerial ignition for prescribed burns in which UAS drop specialized objects used to clear fuel underbrush through targeted, controlled burning to prevent the spread of fire.

In Finland, ERS and EMS broadly consider UAS applications and often collaborate. First responders, Search and Rescue (SAR), mitigating natural disasters such as wildfires, storms, and floods, and technogenic catastrophes are just some of the application area examples. A lot of attention is paid to climate change and the long-term consequences of the disasters, and therefore, a large variety of nature observation and monitoring cases are implemented all around the country, and the number of those grows. The Finnish police is one of the biggest UAS operator among law-enforcing agencies. In addition to the usual police missions, drones are widely used to observe and monitor disaster or catastrophe areas and ensure the absence of non-authorized access.

2.4 Challenges

Based on the current operation environment and constraints, the following challenges have been identified:

1. Overall maturity of aircraft and enabling technologies

   Even though the UAS and eVTOL aircraft technologies have progressed tremendously in the last few years, the desired level of safety for some specific operations is still to be achieved. First, not all aircraft are all-weather resilient. Most aircraft do not operate at temperatures below zero degrees centigrade. Some are certified to operate up to minus ten degrees, and very few to minus twenty. The temperature is sometimes lower in the Nordic countries, and the weather conditions bring additional challenges, such as icing and wind gusts. Similar conditions may appear at higher altitudes in the mountains, and the air density there is even lower, negatively affecting the flight time. Heavy snowfall and heavy rain may reduce flight time or make the flight impossible. When speaking of disastrous situations, the usual range of aircraft capabilities is often insufficient. Optical sensors may not be sufficient when air transparency changes due to smog, fog, or low clouds. Light-based sensors may not operate when the sun is too bright or heavy light emission exposure is present. Aggressive chemical elements may damage aircraft, while heavy radiation or electromagnetic emissions may affect electronics. Some of those external factors may negatively affect aircraft communication and navigation abilities, not to mention the fact that in rural areas and closer to the North or South poles, the quality of those may struggle. The number of technological challenges is vast [35], but overcoming those will be essential for safe public good operations.

2. Airspace integration and design:
   With the maturation of technologies that made UAS more widely available and more consistently stable in performance came the widespread adoption and application of the aircraft worldwide. Their unique characteristics, however, have made it a challenge to integrate operations in the airspace routinely and at scale to date. One of the main barriers thus far has been the ability for operators, in the absence of direct positive control from ATC, to manage UAS conflicts in airspace that is shared and to be able to operate cooperatively with the necessary level of awareness. A major advancement to address this barrier was formally announced by NASA in 2016 with the publication of the first ConOps in which the foundational tenets of UTM were established [36]. The key enabling element for the approach to airspace integration was the ability to use services within a common architectural framework that facilitate information exchanges such that operators can plan and execute missions with strategic awareness of the airspace and surrounding operations with tactical support for nearer term decision making. Through a formal project within NASA's Aeronautics Research Mission Directorate, NASA carried out a multi-year effort in UTM that resulted in an initial implementation of the architecture and testing of procedures that was ultimately transitioned to industry and the FAA for final implementation and policy decisions respectively. The UTM concept and technical elements were further adopted internationally in Europe, Australia, and parts of Asia. While the initial scope of UTM was at lower altitudes in uncontrolled airspace, the intent had always been to broaden its coverage for more seamless integration with the overall airspace. Relatedly, as UTM progressed, the service-based traffic management concept took hold and further extended to the emerging areas of UAM/AAM and Upper-Class E Traffic Management (ETM) [37], which further gave rise to the framework for Extensible Traffic Management (xTM) [38] in which the management services and approaches in each domain were harmonized. A common element across the different management concepts is the Cooperative Area (CA). A CA is an area in which operators can manage their operations with others within the CA structure through adherence to a set of Cooperative Operating Practices (COPs). Many of the challenges that prompted the establishment of xTM, CAs, and COPs are present in disaster response situations as well in terms of airspace integration. Therefore, the xTM construct is equally applicable, but there are added challenges of integration that are unique to disaster response that must be understood and incorporated in both domestic and global contexts.

   Safe and efficient integration of new entrants with existing users at low altitudes is considered a key milestone for the success of public good missions of UAS. There have been different operational concepts, ranging from segregated airspace (layers, operation volumes, corridors), some of which have been proposed in the initial UTM Concept of Operations [37] as well. NASA and JAXA have conducted joint research and flight testing demonstrating that the same concept can be used to manage helicopter missions conducted under visual flight rules (VFR), as long as the necessary situation awareness and information technologies are present [39] [3]. Research on operation volume-constrained VFR disaster reconnaissance missions have shown that airspace segregation contributes to the safe disaster response with minimal increase in the pilot workload [40]. Flight demonstrations and testing have demonstrated the feasibility of the airspace segregation concept and identified some of the challenges which it can pose. Non-segregated tactical deconfliction operations will require separation standards, which are not in place yet.

   Different structures and approaches can be adopted for routine missions. It is essential to design the airspace so that no time-consuming reconfigurations need to be implemented in case there are frequent or routine operations in place. This leaves the airspace open to the routine operations, while allowing nominal air traffic in other parts. For example, recurring mission profiles can be operated, in the European Union, using EASA's categorization of risk levels. Those are categorized as “open”, “specific”, and “certified” [41]. In the “specific” category, recurring mission types can be registered and approved by the respective civil/national aviation authority, potentially easing the process for scheduled/routine missions. Numerous current UAS regulations are risk-based and evaluate the flight based on the way the aircraft is operated and the airspace flown [42]. There are various airspace structures proposed to enable low-altitude airspace operations of versatile aircraft [43]. The service-driven European U-space concept [44] can enable ad-hoc as well as scheduled operations by dedicating a certain block of airspace for highly automated drone traffic, for example between hospital locations, while the conventional flights under visual flight rules (VFR) in the surrounding airspace are not affected. High automation enables a traffic management especially for a larger number of uncrewed aircraft, making use of mechanisms to organize, monitor and optimize the air traffic. In the future, it is expected that U-space airspaces offer a variety of automated services with little or no human interaction required, which would be a crucial prerequisite to have rapid authorization of ad-hoc missions while not affecting safety negatively. Linked to this approach, on the one hand, the European U-space regulation comes with the possibility to restrict drone operations in an assigned U-space airspace when there is the need for air traffic controlled by ATC to enter or traverse the airspace volume, referred to by the term “dynamic airspace reconfiguration”. This especially enables an unhindered emergency response, e.g. by HEMS. On the other hand, a fully collaborative interface between U-space and air traffic management could enable a reconfiguration of the airspace that also works the other way – enabling a corridor for ad-hoc drone missions using previously controlled airspace, in accordance and coordination with ATC. Certainly, this requires a detailed look into the requirements and interfaces, being dealt with in several research projects, e.g. the ENSURE project on ATM/U-space interfaces and airspace reconfiguration service [45].

Further, a potential integration solution for traditional manned aviation lies in the usage of U-space airspace when complying with the e-conspicuity demand [46], enabling an electronic visibility to other U-space users and facilitating the conflict detection and resolution services to allow for safe coexistence of manned and unmanned aircraft.

3. Information sharing

Information and data sharing is not a unique challenge to public good UAS operations. It has been considered key for successful trajectory-based operations (TBO) in the traditional air traffic management domain. Both new entrants and traditional airspace users need to be integrated into the data exchange and coordination processes. Due to the nature of the public good operations, some of which include safety-critical and disaster response flights, each organization/agency manages their own fleet of crewed or uncrewed aircraft. Flight information is shared within the fleet, but not across the agency, which limits the operational efficiency. Airspace integration and strategic planning requires sharing of both pre-flight and in-flight information, including flight intent. Current VFR operations, for example, are characterized by high unpredictability and can pose challenges to other airspace users.

In general, positioning and mission intent data are shared among the aircraft in each organization, but they are not shared in a systematic way with UAS operators, for example. Missions are assigned to manned aircraft in a centralized manner, but the mission assignment to drones happens at a local level (see Figure 2). For an optimal disaster response, full integration and information sharing are necessary.

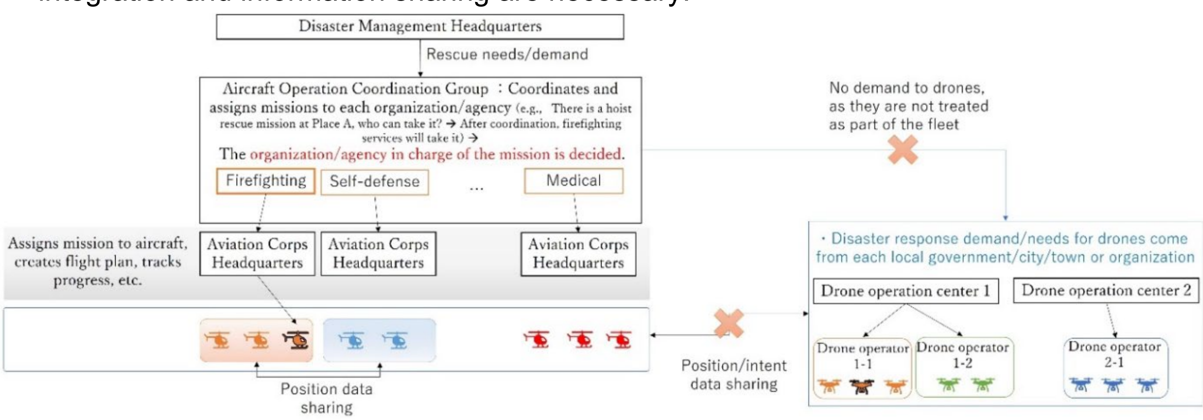

Figure 2 - Sample information and mission assignment flow (based on typical operations in Japan).

4. Situation awareness

   A combination of onboard, enabling, and supportive systems and system and human performance are all necessary to achieve high levels of situational awareness. In disaster response scenarios, situation awareness is a crucial factor in achieving high operational efficiency and safety, and often determines the success of the mission.

5. Mission prioritization

   Crewed aircraft operations are prioritized over drone operations, but this is not necessarily optimal when considering the total disaster response. In the early stages of post-disaster reconnaissance, for example, obtaining information on the damages and people in distress is crucial for the overall disaster response planning and execution. Assuming UAS play a significant role in disaster reconnaissance, missions should be prioritized based on their contribution to the overall response, rather than solely based on the type of aircraft used.

6. Altitude reference/common altitudes

   Current VFR practices (using pressure altimeter to maintain separation from other aircraft, for example) might need to be revisited if some new entrants such as UAS refer to GPS altitude instead. The lack of common reference is a known issue raised by many stakeholders [47], with several potential solutions being proposed as part of the ICARUS project [48].

7. Rule-making and standards

   Regulations, policies and standards are lagging well behind not only in supporting UAS operations in disaster response scenarios but also in a more general sense. For example, the traditional aviation human-centric approach limits the deployment of highly automated and autonomous missions such as evacuating a person with the help of uncrewed aircraft or operating a swarm of drones. Taking the Hungarian system as an example, blood transportation can be divided into two activities: the “regular” collection and distribution and the emergency deliveries. Regular activities will likely not benefit from drone usage, as the volume of transported blood is high (potentially unreasonable payload requirements for a UAS), and the activity is not time-critical; transfusion blood can be safely stored for up to 42 days. Emergency blood supplies are delivered between a central depot and the medical institutions where the demand arises, typically for surgeries, especially when infants and rare blood types are involved. Blood generally does not need to be delivered to the scene of an accident, as the first responders carry a stock with them. Based on preliminary investigations, current drone technology has the potential to reduce delivery times by 10-15 minutes in Hungary. However, although technically the service is feasible, there are regulatory barriers. The Hungarian lawmaking introduced the additional requirement (on top of the EU regulations), that UAS operating in “populated areas” must do so in a previously reserved airspace. As most hospitals lie in urban areas, this is a significant constraint. Note that the term populated area is very loosely defined by law at the moment. Reserving airspace with the appropriate body (currently the Ministry of Defense, State Aviation Department), for drone use can take up to 30 days, This currently represents a regulatory showstopper, as ad-hoc permits can’t be requested with this mechanism in time for emergency response, especially because by law, the blood and transplant services are in the civilian user category, so can’t be operated under the state UAS regulations. The solution could be a revision of the regulations and/or dynamic/real time airspace management.

8. Ground infrastructure

   The UAS need to be deployed fast and efficiently from various locations. However, not enough research and development effort were given to mobile and on-site fast deployable stations.

   Furthermore, all necessary infrastructure related components should not limit operability of considered disaster dedicated UAS. These requirements can create challenges for the system capability to operate on unknown terrain, and ad-hoc missions in particular. For example, the system should be able to assess the risk, specifically: landing, take-off or lifting-on, lifting-off. It should contain implementation of solutions allowing broad situation awareness i.e. for obstacle detection, potential hazard identification and evaluation, determining of prevailing atmosphere conditions etc. Dedicated systems should be autonomous as well as able to cooperate with both human (rescuers) as well as other systems commonly contributing to the disaster response mission.

9. Impact of/on the environment: noise, bird strikes, etc.

UAS operations contained in disaster response are high-priority, emergency missions dedicated to mitigating relevant disaster risks. Assuming sustainability as key criterion standing behind rationality of AAM deployment the following challenges needs to be addressed while definition of requirements with regard to impact on natural environment:

- LCC (Life Cycle Cost) of the AAM system in pre-disaster phase. Due to usual very long time periods between disasters (often several years), the LCC of local systems aimed at it detection should be minimized (best if reduced to the single functionality of other better economically justified systems).
- System reliability and safety during disaster phase. AAM dedicated to significantly contribute to the mitigation of disaster risks should not lead to increase of them. Therefore, solutions oriented on mission reliability (in integrated ecosystem) as well as safe flight termination should be available as preventing i.e. further fire propagation or water/ soil pollution in result of AAM vehicle crash.
- System specification and performance should be adapted to the character of disaster while post-disaster phase to not contribute to the increased cost of disaster. Here both the LCC and reliability aspects needs to be taken into account.

3. AAM Aircraft Applications

3.1 Public Good Missions in AAM

It is said that aviation is currently undergoing a third revolution. After the first flight, followed by the advent of jet engine technology, a confluence of technological advances is now ushering in a new era where new types of aircraft that are electrified and capable of vertical takeoff and landing (referred to as eVTOL) may soon earn their place in the airspace of multiple nations worldwide. These eVTOLs are much larger than drones and are capable of carrying passengers within and between cities and communities (with applications in rural areas) as well as large cargo as an embedded link within the distribution chain. The anticipated technologies onboard these aircraft as well as on the ground (and in the cloud) will eventually rely heavily on higher levels of automation and supporting services to assist in cooperative management of the airspace [49]. Taken together, the types of operations envisioned with these aircraft and their management in the airspace system are part of the larger construct of Advanced Air Mobility (AAM), which includes the concept of Urban Air Mobility [37].

While many of the applications in AAM are considered to be for commercial purposes, significant opportunities have been identified that would be of great benefit as public good missions. According to an assessment published in 2023 [4], some particular AAM public good applications could be: critical infrastructure inspection, post-disaster supplies deliveries on scene and to stranded persons, and rescue missions involving personnel transport (figure below). Another report prepared by SAE International also identified multiple potential applications and relevant challenges for the use of eVTOL aircraft during natural disasters [50]. What makes these missions under AAM unique relative to the use of drones is the ability to carry greater cargo loads for improved logistics in disasters and the ability to transport people and even provide lifesaving services while en route. The benefit of AAM applications in public good missions relative to traditional operations using crewed helicopters and airplanes is the ability to conduct such missions at scale and with-eventually- less reliance on pilots onboard, which reduces risk and allows for continuous operations.

Figure 3 - eVTOL responding to a person in distress (NASA/Graphics).

3.2 Potential applications

Research has indicated a greater support for public good AAM applications than for private and commercial use [51] in Europe. Similar perceptions are seen worldwide, with communities being more supportive of use cases which benefit the public good.

In Japan, there is a strong argument that say AAM should be used for people in mountainous areas, remote islands and other remote communities that cannot be accessed by public transport [52], [53]. This particular application is rooted in the demographics of Japan, where the number of elderly people living in areas with limited transportation means has been increasing. Furthermore, as a disaster-prone country, Japan's early use cases are likely to involve immediate disaster response, in particular transport of people and goods to areas with damaged ground infrastructure, as well as rescue and evacuation. Such applications can be leveraged to boost social acceptance for AAM.

In Hungary feasibility studies were conducted on the applicability of AAM aircraft in the Emergency Response Services, partial results are already published [54]. Hungary's geography is arguably beneficial for the introduction of AAM services, as over 80% of the area is below 200m AMSL and the highest elevation is 1016m. The country is landlocked, so there is no sea access. The climate is typical continental, with low precipitation over the year. Natural disasters are extremely rare, the most common is annual flooding usually in springtime. Based on the feasibility studies it can be shown that introducing a relatively small fleet of 40 aircraft, with modest performance requirements can enhance the EMS activities country-wide: the ratio of population that can be reached under 15 minutes could be potentially increased from 82% to 99%. There are other theoretical studies related to AAM application to other fields, but they are mostly in their preliminary stages. There are currently no active vehicle or service development projects available openly.

In Germany, relevant crisis situations include floods, forest fires, storms, snow conditions, and heat wave/drought. The previously mentioned example of the Ahrtal flooding in 2021 stands out, but also the Elbe river experienced a heavy flood in the early 2000s, and, most recently, the flooding in Baden-Württemberg and Bavaria in 2024. Additionally, winter storms and hail storms have been the cause of broad damages across the country, raising damage in the billions. A focus of research is currently on rural flooding and (sub)urban storm damages. In previous activities, earthquake disaster response in a simulated earthquake scenario in the Alps has been demonstrated in a large-scale exercise, where aerial images taken from a UAS demonstrator proved to be useful for first responders [55].

In Finland, applications of eVTOL and Emerging Technology Aircraft (ETA) by DRS and EMS are yet at the level of research projects. For example, using eVTOL and ETA along with UAS are seen as a supplementary means of enhancing the capability of HEMS. The feasibility of such applications, the business models, and the economic and environmental effects are still to be explored, even though preliminary studies indicate attractive perspectives [6]. It is possible to anticipate economically feasible and environmentally vital eVTOL and ETA operations for emergency delivery or human transportation, especially in difficult-to-reach areas such as remote rural areas and islands.

In the United States, significant attention is being given to the application of AAM to public good missions. The new eVTOL aircraft will likely be a valuable complement to emergency medical

transport flights that are currently carried out by helicopters. The delivery of life saving supplies, particularly in large-scale situations, is an added benefit to the logistics challenges that typically emerge. The staging of equipment and supplies prior to adverse events and movement during active response is another area in which AAM operations are considered. Post-disaster resupply as well as medical personnel transport and injured persons extraction/rescue are additional areas of AAM applications. The sample applications can apply across a variety of cases ranging from routine medical/accident transport to wildfire, flooding, hurricane, etc. response.
In Brazil, there is high interest on the use of eVTOLs for aeromedical transport for both emergency and non-emergency care, particularly considering the significant growth of these operations in the country since the pandemic. Other AAM applications under consideration focus on improving accessibility to remote areas, particularly in the Amazon region, as well as the response to frequent flooding and landslides events.

3.3 Challenges for AAM public good applications

Many of the challenges for UAS implementations are valid for AAM as well. Some unique or highlighted challenges are summarized below.

1. Overall maturity of aircraft and enabling technologies

   Current AAM aircraft might not have sufficient range to perform many of the missions which are now assigned to crewed helicopters, due to the limited battery performance and range.
2. Charging and ground infrastructure

   Charging infrastructure needed for AAM aircraft: difficult to provide in remote areas and/or on demand. This constraint needs to be considered during the strategic placement of ground infrastructure along with efficient fleet management to ensure timely response.
3. Airspace management and coordination with crewed aircraft

   More coordination will be required for AAM aircraft as they will likely be in closer in proximity to the other crewed aircraft. There is a need for flexible airspace and traffic management strategies to facilitate safe and effective missions while minimizing disruption to existing aviation operations.
4. Operations in adverse weather conditions

   Operations need to be robust to adverse weather conditions that can prevail during natural disasters, such as strong winds, heavy rain and low visibility. This requires advanced navigation capabilities, more resilient aircraft structures and avionics and real-time weather sensing and avoidance technologies to optimize flight operations under dynamic weather conditions.
5. Public acceptance

   Consideration of stakeholder and public acceptance levels, among other factors, will be key for the successful implementation of AAM technologies and integration of AAM vehicles.
6. Operations diversity

   Additionally, each particular use case has its own set of unique operational requirements and key challenges to be overcome. In the context of aeromedical transport (air ambulance), for example, electric aircraft endurance and charging time have been found to be key issues [1]. The authors emphasize that aircraft manufacturers and air ambulance service providers must consider technological advancements and operational procedure changes aimed at decreasing charging times and extending electric range, exploring innovations like battery swapping and alternative fuel aircraft, to maintain a high level of operational readiness and reliability, aligned with the standards of traditional aircraft currently serving the market.

4. Ongoing aviation research on public good missions

As indicated in the scientific assessment prepared by the IFAR members [1], the focus on public good mission applications of novel aircraft has been ongoing due to the high acceptance, numerous potential use cases and involvement of local and central governments. The apparent benefits for the communities have triggered research at many research institutions and universities as well.
In Japan, for example, the Japan Aerospace Exploration Agency (JAXA) has developed the Disaster Relief Aircraft Information Sharing Network (D-NET) [56]. First, to speed up data acquisition and reduce the errors during voice transmissions when assigning missions, JAXA developed a system for real-time data transmission. The system enables a real-time connection between the pilot of a disaster

relief aircraft and a ground server. Based on that foundation, integrated operation technologies have been developed. The technology objectives are to acquire data efficiently from available sources (e.g., satellites, helicopters, and unmanned aircraft systems), analyze these data in order to provide optimal resource allocation and flight trajectory plans for response vehicles, which can in turn be integrated and applied in actual rescue operations. Leveraging D-NET's technologies, JAXA has joined efforts with the National Aeronautics and Space Administration (NASA) since 2016 to explore improved airspace management for disaster response through the integration of manned aircraft and small Unmanned Aircraft Systems (UAS) through the use of NASA's UAS Traffic Management (UTM) system. To drive the innovation in improved response, JAXA and NASA have successfully connected respective systems and conducted a series of live flight tests first as part of a large-scale disaster drill and later in dedicated research flights. In each case, the D-NET and UTM systems were connected and exchanged data in real-time, which supported the planning and tracking of manned and unmanned operations. More recently, the work has been focused on the safe integration of UAS and helicopters in active wildfire disaster response operations. Leveraging D-NET's onboard mission support technology and NASA's expertise in wildfire operations, situation awareness technology was developed and verified through real flight testing. It was confirmed that real-time awareness of the UAS operation airspace helped the helicopter pilot plan and execute a safe mission and minimize the flight time loss due to potential interference of the UAS (see Figure 4 below).

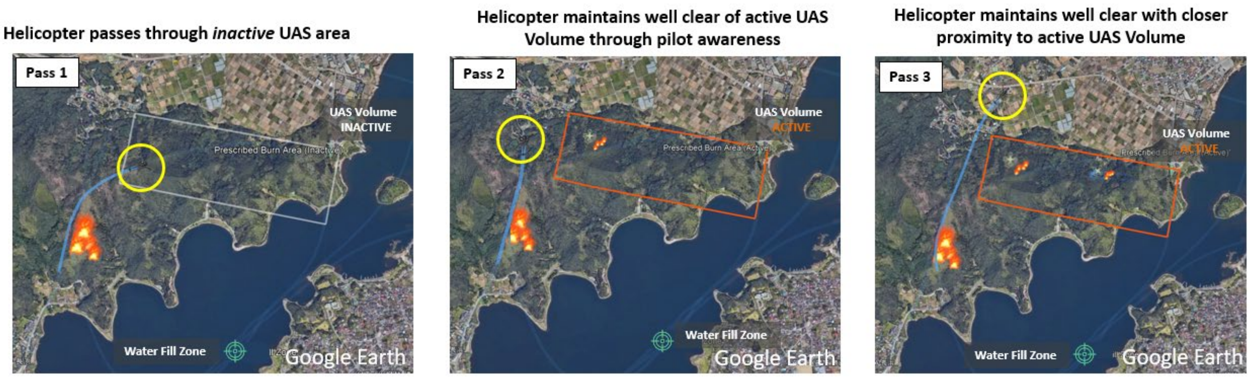

Figure 4 - Flight test results from joint JAXA/NASA testing.

Leveraging the same D-NET platform and pilot expertise in disaster response, JAXA has been focusing on post-disaster reconnaissance missions and researching operation volume-constrained VFR operations as a potential solution for integrated operations as well [57] [40]. The most recent efforts are part of a K Program project, sponsored by Japan Science and Technology Agency, in which JAXA is working with industrial and academic partners to develop operation technologies for crewed and uncrewed aircraft based on versatile data sources such as mission status and weather, and integrate those to aid safe and efficient integrated operations [58].

In Poland, Lukasiewicz Research Network – Institute of Aviation is strongly focused on exploitation of technological opportunities coming from both operational capabilities of drones and drone swarms as well as increasing computational performances resulting from development of AI and Machine Learning solutions. An example of the research is the *Mobile system and device for managing the movement and evacuation of a set of moving objects*. The essence of the novelty of the technical solution is the use of a swarm of drones for dynamically optimized management of the movement of a set of independent, autonomous objects. Drones can be used to influence moving objects, monitor their flows and assess the effectiveness of the influence. The drone system verifies the effectiveness of its own operation and adjusts subsequent steps to maximize a given goal or meet a given criterion. The system can manage the movement of people, animals, guided and unguided mobile devices such as autonomous cars as well as other drones, etc. The system is especially dedicated to the evacuation of people from endangered areas. Drones influence targeted objects using visual and audio signals, radio communication, and physical blocking of the road. Imaging the movement of managed objects is carried out using drones equipped with multispectral cameras, Doppler radars, optical and ultrasonic sensors. The system is autonomous. The main components of the system are:

- Monitoring and executive drones. They implement the evacuation plan and monitor its progress in terms of meeting the set goals and criteria.
- Ground station providing a user interface and allowing the definition of input data, supervision of the system and influencing the course of the task being performed.

- Drone pod. Drones take off from a mobile pod installed on the roof of vehicles responsible for safety in public places.

The system can be integrated with other systems considered within crisis management activities in urban areas. System concept is presented in Figure 5.

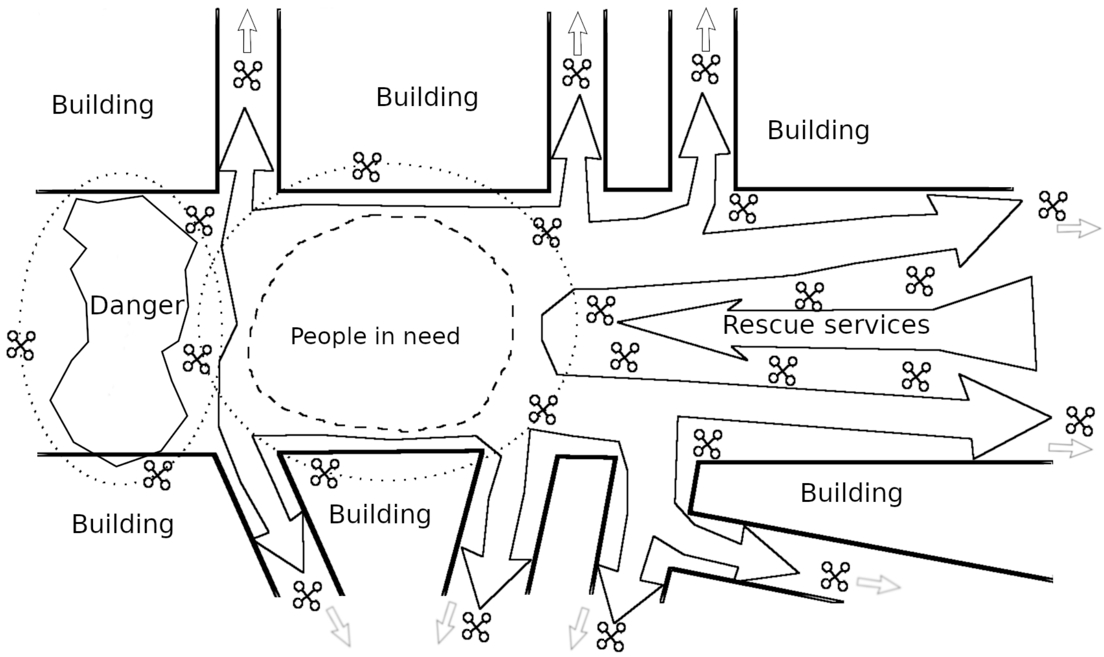

Figure 5 - A mobile system and device for managing the movement and evacuation of a set of moving objects developed in Institute of Aviation in Poland.

VTT Technical Research Centre of Finland has a long history of researching and developing disaster information, safety, and response systems, as well as nature observation and monitoring systems, enabling technologies, cases, and applications. Current research includes U-space/UTM and UAM enablers and scenarios, e.g., the four EMS scenarios of the AiRMOUR project, Human-Machine Interaction (HMI), wireless aircraft communication and radar technologies, automation and autonomy, wildfire monitoring with drone swarms, monitoring of floating waste and tailing ponds of mines, hyperspectral imaging of flora and the other similar applications.

Current UAS research at the German Aerospace Center (DLR) includes the RESITEK project (2024-2026), which aims to combine the strengths and capabilities of numerous institutes at DLR towards a combined product that demonstrates the possibilities and benefits of several disaster relief methods and technologies, including aviation. The project builds on collected data from past catastrophes and forecast tools available at the institutes. From the airside perspective, focus is given on coordinated mission planning for all airborne resources, including UAS, using robust communication and navigation tools, and a central visualization of the developed methods and process chains, with final demonstrations in deployment scenarios of various drones, complemented with a helicopter simulation. The scenarios envisaged for the demonstration activities are a flooding in a rural environment (similar to the Ahrtal flooding) on the one hand, and a heavy storm in an urban environment on the other hand. The objective is to apply the developed demonstration system to each scenario with only little need to adapt or modify software and/or hardware.

Further, the SAFIR-Ready project (2023-2025), funded by the European SESAR3 research program, focuses on rapid authorization for ad-hoc public good drone missions, especially for time-critical medical applications and infrastructure inspection flights in preparedness and response phases. To demonstrate the solution, stakeholders from various countries are involved in the scenario creation. The scenarios focused on use cases in Braunschweig, Germany, are derived in collaboration with the municipal hospital of Braunschweig and the Braunschweig-Wolfsburg airport and aim to exploit the capabilities of central and surrounding hospitals with routine and ad-hoc medical drone missions. The scenarios include the transport of urgent equipment and tissue samples, transport of medication, and inter-hospital logistics both in the urban short-distance and rural long-distance environment (see Figure 6).

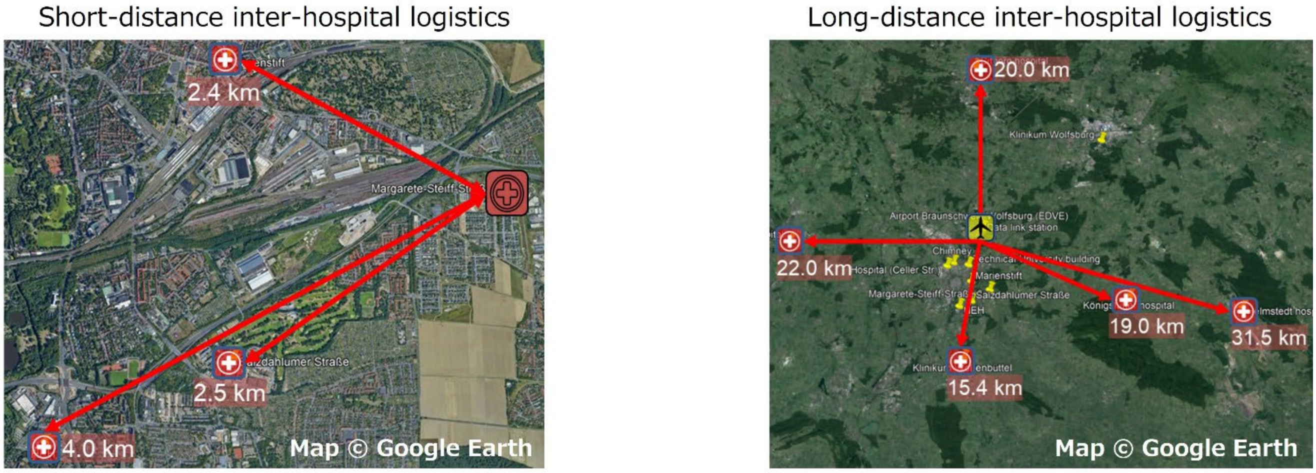

Figure 6 - Inter-hospital logistics using drones, short (left) and long (right) distance.

At NASA in the United States, a number of research activities are ongoing across the agency in support of public good missions. Two key Projects fall under the Aeronautics Research Mission Directorate’s Airspace Operations Safety Program: Advanced Capabilities for Emergency Response Operations (ACERO) [59] and System Wide Safety (SWS) [60].

The ACERO Project is focused on tackling the challenges and barriers that prevent fully integrated air operations in large-scale wildfire response efforts as well as overcoming the blockers for autonomous night missions. One of the key integration areas with a current focus is on the integration of drones and crewed operations (e.g., helicopters) in the same airspace. Others address the challenges related to the prediction, detection, tracking, and monitoring of wildfires as well as those related to aerial suppression support once in an active situation. The objectives of the ACERO Project in addressing the stated challenges is the demonstration of airspace management technologies, the development and demonstration of new mission capabilities, the integration of additional NASA capabilities from NASA’s Science Mission Directorate, as well as leveraging public-private partnerships for the development and testing of new technologies and approaches to wildfire response (initially).

Figure 7 - NASA’s ACERO Project

The System Wide Safety Project is focused on understanding the impact of the increased complexity of aircraft and airspace operations on safety, the assessment and mitigation of risk, and the extension and application of the In-Time Aviation Safety Management System (IASMS) with its enabling set of Services, Functions, and Capabilities (SFCs). The breadth of the SWS Project spans from traditional air operations to newer entrants such as drones and their management within the UAS Traffic Management (UTM) domain. More recently, the Project began a series of Safety Demonstrators with the aim of applying the established IASMS to disaster response operations. The goal of the Safety Demonstrators is to identify the requirements and standards necessary for the ability to monitor, assess, and mitigate risks that emerge in disaster situations through the application of the IASMS and SFCs. The initial use case for the series is on wildfire response [61], but the objective is to look beyond wildfires to broader situations such as hurricane response.

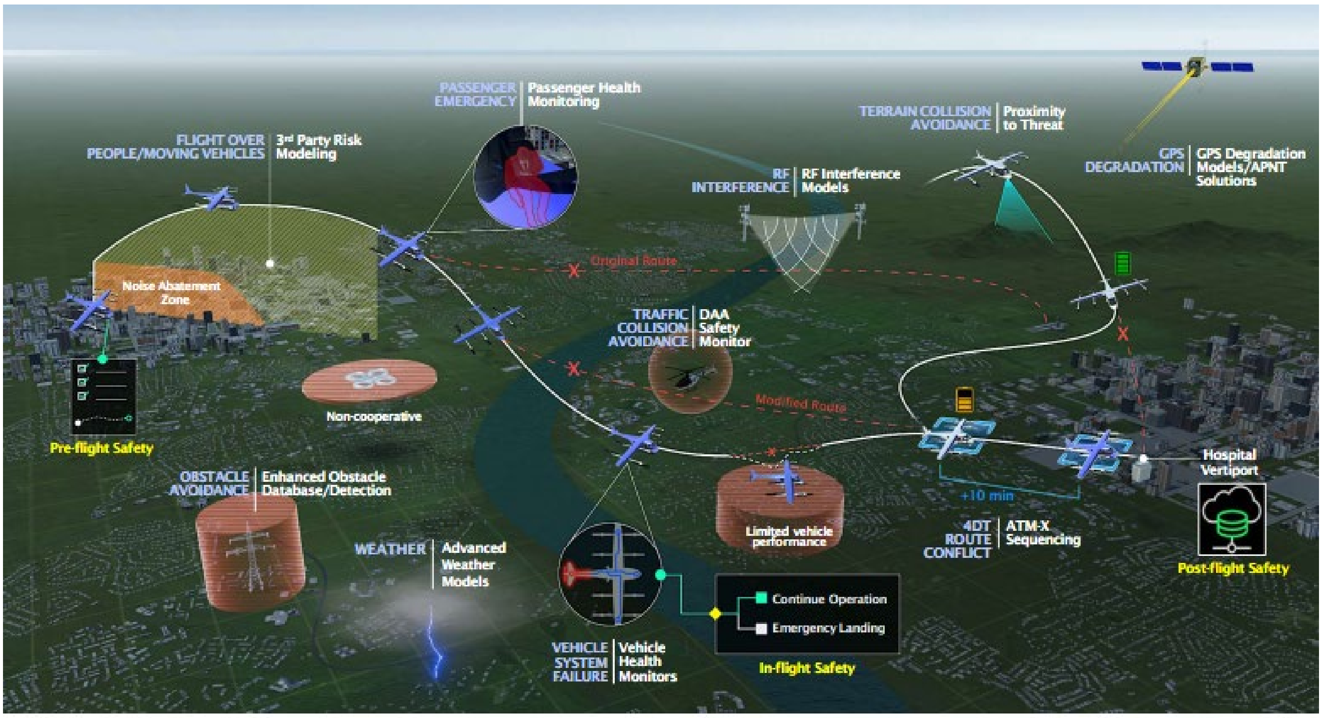

Figure 8 - NASA's System Wide Safety Project

At ITA (Brazil), there are ongoing research efforts to address the challenge of safely integrating AAM operations into controlled airspace, which is key for the successful roll-out of public good missions enabled by these novel aircraft types. This includes the design of solutions for envisioned novel traffic management capabilities, such as conflict management and dynamic airspace geofencing, and the quantification of the impacts of these solutions and associated requirements on the performance of flight operations, particularly in terms of safety and efficiency [62], [63].

5. Concluding Remarks

Novel aircraft can enhance the public good and disaster response thus contributing the well-being of the general population not necessarily benefitting from the traditional aviation technologies. The international team consisting of 7 countries representatives agreed that public good applications of UAS are likely to increase in both variety and intensity, once the technical, operational, regulatory and societal acceptance challenges are solved. Furthermore, AAM aircraft are likely to substitute some of the existing aircraft in public good missions and service some new ones as well, contributing to time-critical operations. While there are significant challenges in the application of advanced aerial assets in disaster response, the benefits far outweigh those challenges and are thus deserving of a concerted and coordinated global effort.

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7. Copyright Statement

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