24/7 Wildland Fire Aerial Operations Airspace Management System Concept of Operations

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Parimal Kopardekar	CS, NASA Ames Research Center
Min Xue	CS, NASA Ames Research Center
Mark Bathrick	CTR, Metis Technology Solutions
Gilbert Wu	CS, NASA Ames Research Center
Kyle Zanzi	CTR, Metis Technology Solutions
Steven Weidner	CTR, Metis Technology Solutions
Alexander Sadovsky	CS, NASA Ames Research Center

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1 Executive Summary

Wildland fires in the United States have steadily increased in expanse and destruction in recent decades due to a mix of various concurrent issues. This situation has challenged traditionally successful wildfire response efforts, and in the top 2% of most severe incidents, has had them outmatched. A closer examination of firefighting methodologies and equipment seeking to identify areas for reinforcement and increased effectiveness is underway by many agencies nationwide with relevant expertise. The National Aeronautics and Space Administration (NASA) Airspace Operations and Safety Program (AOSP), under the Aeronautics Mission Directorate (ARMD), aims to provide expertise and recommendations on safe and efficient airspace and air traffic management [1] that would support wildland firefighting operations and their continuous improvement. Agency-wide, NASA has a legacy of delivering novel solutions backed by its supporting research and demonstrations. Through its 2024 induction into the National Wildfire Coordinating Group (NWCG), and with ARMD's close collaboration with the Federal Aviation Administration (FAA), the agency is well-positioned to interface with the relevant wildland fire aviation stakeholders to tackle this problem with a modern, collaborative approach.

It is important to understand that ground firefighters are the cornerstone to successful fire suppression. However, the inherent complexities of managing a dynamic and often smoky airspace, coupled with stringent regulations designed for traditional aviation, prevent 24/7 operations thereby withholding the necessary support and tools these ground firefighters need to do their job. While emerging technologies like UAS are utilized on fires today, and night operations have seen a handful of trial programs, a ubiquitous and full integration of mixed crewed and uncrewed operations requires a more sophisticated cooperative airspace management system to maintain the level of risk and safety expected by fire agencies as UAS becomes more commonplace.

This Concept of Operations (ConOps) document outlines ARMD's "future state" vision for aerial firefighting, examining three mission types: (1) remote sensing (mapping) of fire/hotspots and assets; (2) logistics support (deployment, resupply, and emergency extraction); and, of course, (3) suppression efforts (airspace coordination, and payload drops of water, retardant, and aerial ignition canisters for backburns). Performing all three mission types with concurrent crewed and uncrewed vehicles in 24/7 degraded visual environments (DVE) requires air traffic management. This means flying with electronic conspicuity and conducting operations beyond visual line of sight (BVLOS). ARMD's Advanced Capabilities for Emergency Response Operations (ACERO) project envisions the future state firefighters will use a field-deployable cooperative airspace management system to support incident command in planning and coordinating aerial operations, and has begun demonstrating early versions of such a concept.

This vision aligns with the intent of the recent Empowering Commonsense Wildfire Prevention and Response Executive Order (EO) of June 12, 2025 and the Restoring American Airspace Sovereignty EO of June 6, 2025 [2], [3]. This ConOps assumes implementation by the firefighting agencies after technology transfer from NASA's ARMD, along with regulation by the FAA informed by ARMD's recommendations developed from a series of field demonstrations.

2 Introduction

2.1 Background and Importance

Wildland fire aviation technology and resources have been instrumental in wildfire prevention, mitigation, and response strategies in the United States for nearly a century [4]. While aerial resources are just one of the many tools employed to support the objectives of wildland fire management (namely, ground firefighters), they have become a prominent and widely relied upon element of the nation's response to wildfires. Consequently, current efforts to address the national wildland fire threat require a swift, aggressive, and comprehensive examination of all aspects of aerial firefighting. This includes evaluating processes, standards, and technological advancements to enhance their safety, effectiveness, and efficiency.

In July 2022, at the request of the Office of Management and Budget (OMB), NASA initiated a comprehensive project to unite the interagency wildland fire community. The objective was to develop a ConOps for a future state of wildland fire prevention, mitigation, and suppression. To achieve this, NASA assigned ACERO the research task of conducting extensive interviews, tabletop sessions, and workgroups with various partners, including interagency, industry, academia, and philanthropic organizations. This collaborative effort involved thousands of hours of interaction with hundreds of partners, culminating in an Interagency Interim Wildland Fire Management ConOps Workshop in March 2024.

Following the workshop, the NASA team received valuable feedback from participants and key stakeholders. This feedback helped narrow and sharpen the focus of the ConOps, enabling the examination of the current limitations and the desired future state of 24/7 Wildland Fire Aerial Operations Management. Stakeholder consensus emphasized that this area demonstrated the greatest need and potential return on investment in bolstering support for firefighting personnel and the communities they protect. Stakeholders believed that implementing improvements in wildland fire airspace operations management to address current gaps and limitations and realize the desired future state would lead to significant improvements in wildland fire management effectiveness, safety, and efficiency.

This ConOps also addresses relevant airspace operations management priorities outlined in three recent drone, airspace, and wildfire-focused Presidential EOs: (1) Restoring American Airspace Sovereignty—EO 14305 [3], (2) Unleashing American Drone Dominance—EO 14307 [5], and (3) Empowering Commonsense Wildfire Prevention and Response—EO 14308 [2].

The goal of this ConOps is to develop a community-informed NASA ARMD document that guides consistent identification of operation priorities, technology adoption, and programmatic alignment for national needs in aerial firefighting. Ideally, the recommendations in this document should serve as a guide for further development and mission design over the coming decades to support the advancement of wildland firefighting airspace operations management.

2.2 NASA Capabilities and Relevance to Wildland Fire

Over the past 40 years, NASA Aeronautics has been conducting research, development, and technology transfer of activities in support of air traffic operations. NASA tools such as the Traffic Management Advisor, Surface Movement System, and Integrated Arrival, Departure, Surface Systems have improved efficiency of airspace operations and throughput at airports. Furthermore, NASA's concepts and technologies have been instrumental in enabling new entrants, particularly drones into the National Airspace System (NAS). NASA developed standards for command-and-control (C&C) communications and detect and avoid (DAA) to enable larger Uncrewed Aircraft Systems (UAS) in the national airspace system (NAS). NASA also developed UAS Traffic Management (UTM) to safely enable beyond visual line of sight (BVLOS) operations of small UAS (sUAS) at scale in the NAS. The UTM-based BVLOS operations have already started at a key site operation in Dallas, Texas.

Leveraging that expertise, NASA plans to address the pressing needs of safely enabling aerial operations for monitoring, suppression, and logistics support for wildfire management under AOSP. This is particularly important in DVE and crucial to enabling aerial wildfire management activities to run 24 hours, 7 days a week. The concept of the Air Tactical Group Supervisor (ATGS, or Air Boss) managing a significant increase in UAS must be supported by a novel airspace management tool to enhance safety and continuity of operations. Conceptual origins of a cooperative airspace management system are documented in NASA's original patent related to UTM (Patent US-10332405-B2) [6]. In that patent, portable and persistent UTM systems were proposed. The original idea of a portable airspace system to manage UAS was proposed by Parimal Kopardekar in 2014 [7]. A portable system is particularly useful given that airspace above the largest wildfires often receive a temporary flight restriction (TFR) where only participating aircraft may enter. Because mixed crewed and uncrewed aircraft operating with increased traffic density carries a corresponding increase in risk, already having a TFR in place is ideal to add increased control for participating aircraft, and is likewise assumed to be a prerequisite for operating UAS in DVE in the near-to-mid-term. However, that is not to say that UAS will never operate without a TFR, especially as the NAS adapts around other UAM models.

2.3 Scope: Air Operations in Active Fire; Initial and Extended Attack

Effective wildland fire management includes various activities during all three phases: Pre-Fire, Active-Fire, and Post-Fire. These activities collectively form an integrated "system of systems." Addressing each phase and the seven interconnected links in the wildland fire management chain (1-Prior-year Assessment, 2-Active Risk Mitigation, 3-Dynamic Risk Assessment, 4-Timely Ignition Detection, 5-Rapid Initial Attack, 6-Extended Attack, and 7-Recovery), shown in Figure 1, is beyond the scope of this document.

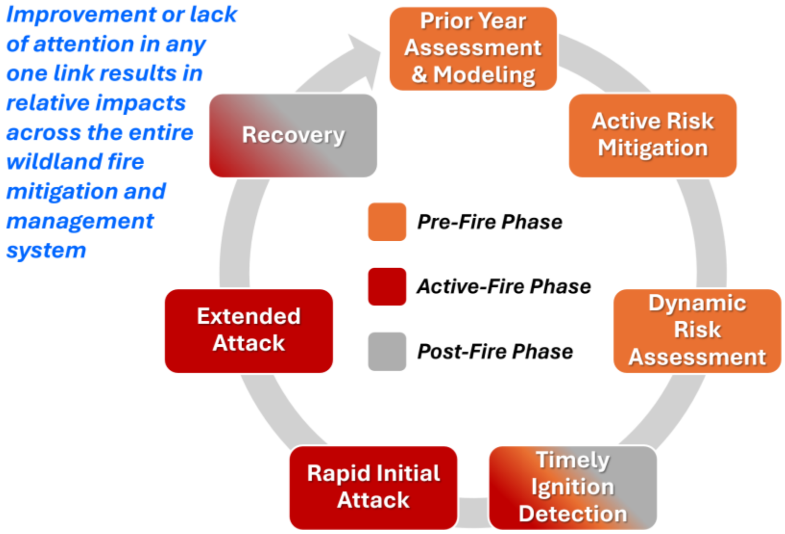

Figure 1 - The three wildland fire phases and seven interconnected system links.

Aviation has historically played, and continues to play, a significant role in supporting wildland firefighters and the communities they safeguard. This role is the central theme of this ConOps, which will concentrate on airspace management and operational technologies that have the potential to add to the safety, effectiveness, and efficiency of wildland firefighting operations. While aviation has been used in support of all wildfire phases and system-of-system links, this ConOps will specifically focus on air operations during the Rapid Initial Attack and Extended Attack system links under the active fire phase. It is within these links that airspace management demands are at their most significant and intricate and thus offer substantial return on investment. Note that while prescribed fires are conducted as part of the Active Fire Mitigation link in the pre-fire phase, they are treated as active fires during their operational phase.

3 Current State of Aerial Operations in Wildland Fire Management

3.1 Entities with Wildland Fire Management Roles in the U.S.

Wildland fires, like other natural phenomena, transcend governmental and jurisdictional boundaries. Effective wildland fire management must be highly responsive and dynamically flexible like other types of emergency response services. Wildland fire management is complex and is influenced by various stakeholders, including such competing land management interests as recreation, grazing, agriculture, threatened species, mining, power, transportation, water quality, and distribution.

Federal Stakeholders: At the federal level, the U.S. Department of the Interior (DOI) and the U.S. Department of Agriculture (USDA), through the U.S. Forest Service (USFS), lead the nation's wildland fire management efforts. The DOI manages the wildland fire response for nearly 500 million acres of national parks, wildlife refuges, preserves, rangelands, and Indian reservations. The DOI's wildland fire management program comprises the Office of Wildland Fire (OWF) and four bureaus: the Bureau of Indian Affairs (BIA), the Bureau of Land Management (BLM), the National Park Service (NPS), and the U.S. Fish and Wildlife Service (FWS). The USFS carries out wildland fire response across 193 million acres of the National Forest System. Additionally, the agency has stewardship responsibilities for over 600 million acres of forestland, including more than 400 million acres of private forestlands. USFS wildland fire prevention and management responsibilities are shared across the National Forest System, State and Private Forestry, and Research and Development Deputy Chiefs and their organizations. Other federal agencies that are involved in wildland fire prevention, mitigation, and management include the Department of Commerce (DOC), which includes the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS), the Department of Defense (DOD), the Department of Health and Human Services (e.g., the Centers for Disease Control and Prevention (CDC), the Department of Homeland Security (DHS, Federal Emergency Management Agency (FEMA), U.S. Fire Administration, the Environmental Protection Agency (EPA), NASA, the National Science Foundation (NSF), the Office of Personnel Management (OPM), and the FAA.

The Stakeholders in the Locale of the Wildfire: Wildfires in the U.S. are a national concern, but their impacts are localized. Data from the National Interagency Fire Center shows that between 2000 and 2019, nearly 2,000 local communities experienced wildfires spanning over 100 acres within a two-mile radius, including nine major cities with populations over 500,000 [8]. Local fire departments are responsible for the initial attack response for nearly 80% of all wildfires [9]. While every state and U.S. territory faces a risk of wildland fires, those with the highest risk have established robust, well-funded wildland fire capabilities. Coordination between state and federal wildland fire agencies is facilitated through the National Association of State Foresters (NASF), which comprises representatives from each state, U.S. territory, and the District of Columbia [10]. Individual state organizations with wildland fire responsibilities collaborate closely with local governments and fire departments to coordinate regional, district, and community wildfire prevention, mitigation, and management efforts.

Stakeholders Driven by Tribal Interests: With over 70 million acres of recognized Tribal land areas spread across dozens of states, Tribal governments play a significant role in wildland fire prevention, mitigation, and management [11]. However, given the 574 currently recognized Native American tribes in the U.S., collaborating with each tribe on wildland fire issues would be challenging [12]. Like the states, the tribes collaborate with their federal partners through a formal consortium group. For the tribes, this group is the Intertribal Timber Council (ITC) and its Fire Sub-Committee [13].

Industry, Academia, and Philanthropic Stakeholders: Given the significant economic impact from wildland fire and the huge sums of government funding that are applied to preventing, mitigating, managing, and recovering from wildland fires, it’s also not surprising that private industry, from small companies to large multi-nationals, also have an interest and desire to assist in meeting the challenges of this national issue.

Stakeholder Complexity and Diversity Affects Decision Speed: The complexity of bringing these diverse groups together and effectively and efficiently focusing their efforts to address this complex, dynamic, and growing national issue is no easy task. This challenge has also been recognized and addressed through the June 12, 2025 Empowering Commonsense Wildfire Prevention and Response EO.

3.2 Challenges in Technology Adoption

At a March 2024 NASA-sponsored Interagency Wildland Fire Management ConOps Workshop, government, industry, academic, and philanthropic participants highlighted issues that presented the most significant challenges in the current state of wildland fire operations in the U.S. and the greatest obstacles to future progress. These challenges fell into the following four categories, in order of relative significance:

TABLE 1 - OBSTACLES TO TECHNOLOGY ADOPTION

Topic Area	**Obstacles**
Organizational Alignment and Leadership	Ensuring leadership aligns with acquisition goals and priorities is crucial. Lack of direction, conflicting priorities, and ambiguous authority hinder well-defined requirements.
Policies and Processes	Inconsistent or outdated acquisition policies and processes create confusion and inefficiencies. Wildland fire management acquisition often involves multiple agencies, making it challenging to translate agreed-upon requirements into consistent procurements. Agency funding and cross-agency payment protocols further complicate matters.
Handling of Human Capital	Skilled personnel who understand the acquisition process and can translate user needs into clear requirements are crucial. To maintain firefighter retirement coverage, wildland firefighters are required to remain within limited, specialized jobs. Because of these requirements, wildland firefighters rarely have acquisition and requirements determination education and experience and are generally unwilling to step outside of their retirement-covered positions to obtain other skillsets.
Management of Knowledge and Information	Accurate and up-to-date information is crucial for effective determination of requirements. Agencies must manage existing system knowledge, lessons learned, and industry best practices. Organizational issues affecting interagency wildland fire community requirements also impact the agencies’ knowledge and information management systems.

3.3 Wildland Fire Aircraft

Each year, Federal and State Agencies employ hundreds of aircraft in support of wildland fire use cases [14], [15]. For decades, over 95% of all aerial firefighting aircraft and pilots have come from contracted commercial vendors, not from federal or state staff or aircraft fleets. This practice has provided the wildland fire agencies with an efficiently scalable and highly professional cadre focused on the task of aerial firefighting. These contractors and their equipment are all certified before the fire year and directly overseen by government employees. Between the years 2011 and 2021, USFS and DOI issued an average of 148 aviation contracts annually [16], [17]. This collaboration between the government and the private sector has proven quite successful. It preserves government oversight of a demanding and dynamic wildland firefighting mission support function. The number of aircraft and the diverse array of supporting contract vendors, however, requires significant agency management to ensure safety and performance, as the Federal Aviation Administration is not chartered, staffed, or funded to oversee Public Aircraft Operations (PAO), which are defined to include firefighting [18].

3.4 Wildland Fire Airspace Management Operations

Ultimately it is firefighters on the ground who contain and extinguish wildfires. However, aviation assets are indispensable tools in contemporary wildland fire management, offering capabilities that are often unattainable by ground crews alone. Aircraft perform various types of missions, such as remote sensing, suppression, and logistics. Safe and effective management of airspace during wildfires is paramount to realizing aviation's full potential to contribute to these applications (Figure 2).

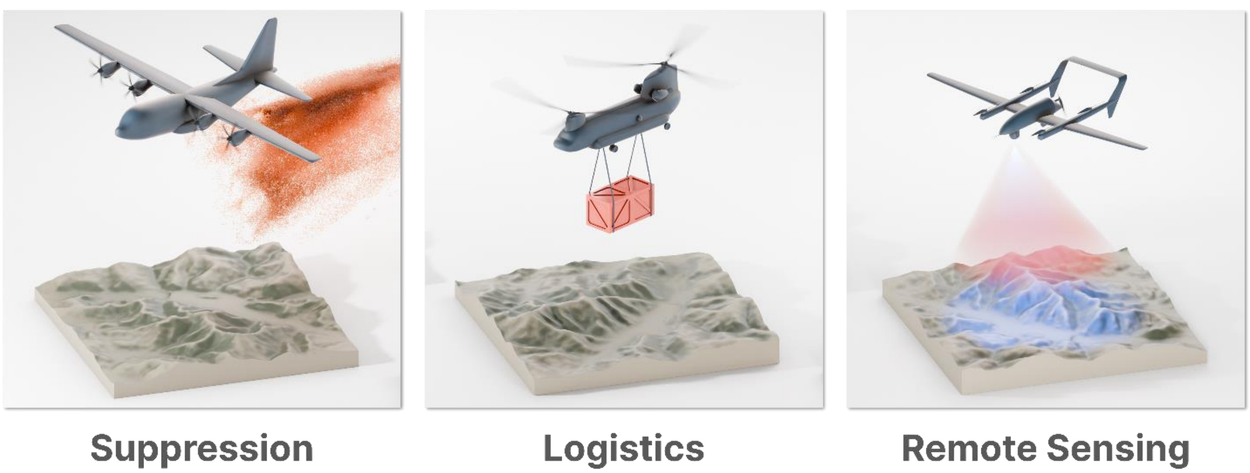

Figure 2 - Aviation wildland fire management use cases.

To understand the complexities and challenges of current wildland fire airspace management operations in safely and effectively supporting these use cases, one need only consult the NWCG Standards for Aerial Supervision, PMS-505 [19].

> *Aerial firefighting occurs in a very dynamic environment. Firefighting aircraft often work in close proximity to each other, ground personnel, and surrounding terrain. This is routinely accomplished under conditions that are less than ideal as aircrews contend with high temperatures, wind, turbulence, and visibility restrictions caused by smoke and terrain.*

> *Furthermore, firefighting aircraft, in contrast to most commercial aviation, must provide their safe separation. It is for these reasons that airspace coordination is of the utmost importance to safety. Though the aerial supervisor is responsible for overall control of aircraft on an incident, it is incumbent upon all aircrew personnel to participate in this endeavor by adhering to the rules set by policy and the instructions given by the aerial supervisor.*

3.4.1 Inter-Aircraft Coordination and Communication

With an average of 70,000 wildfires per year (1983–2022) occurring across disparate areas across the country and often in remote locations, wildland fire managers have been forced to develop airspace management procedures and protocols that can be implemented where traditional airspace management coverage may be spotty, absent altogether, or unable to scale to accommodate the urgency and/or load of additional aircraft that must be brought in to fight the fire. To enable this coordination and control of aircraft anywhere and under any conditions, current wildland fire airspace management relies on horizontal, vertical, and temporal separation. Holding patterns and initial points (IPs) are established on visually significant landmarks to overcome the lack of navigational aids available within the cockpit of some smaller and older single-engine air tankers (SEATs), and ingress and egress routes are defined for aircraft sequencing and separation. Clear radio communication among participants are crucial for effective coordination and separation. The ATGS typically flies above all other firefighting aircraft, monitors multiple radios to ensure smooth communication.

3.4.2 Incident Occurrence and Statistics

Despite significant documentation and regular reviews of wildland fire airspace management procedures, the required training for all participants, and regular confirmation of pilot competency by government pilot inspectors, the wildland fire airspace has repeatedly proven to be among the most hazardous airspace environments in government aviation operations. A review of the DOI Aviation Safety Summary and Annual Reports from 2008 through 2022 bears this out; documenting numerous "near-miss" encounters between firefighting aircraft, accidents involving fatal controlled flight into terrain (CFIT), and fatal mid-air collisions of aircraft both during day and clear-air firefighting operations [20]. Aircraft mishap rates in the wildland fire mission have historically exceeded mishap rates in other DOI mission areas, including those with similar hazard and risk profiles (e.g., search and rescue, low level wildlife surveys, extended overwater support missions). A 2015 CDC study of aviation-related wildland firefighter fatalities in the US between 2000 and 2013 found that across the wildland fire community, 78 deaths occurred in 41 separate mishaps involving 42 firefighting aircraft, with 45% of those resulting from midair collisions, failure to maintain terrain, water, or obstacle clearance, or pilot loss of control [21]. These adverse trends in wildfire aviation safety continue today. In 2019, while working a DOI managed wildfire, two single engine air tankers collided, resulting in the loss of both aircraft and pilots. And on August 7, 2023, two CalFire firefighting helicopters collided in mid-air during daytime operations in Riverside County, CA, resulting in three fatalities [22].

3.4.3 Manual and Labor-Intensive Airspace Management Processes

Wildland fire airspace operations management processes have remained largely unchanged since the first aircraft dropped water on a wildfire in 1930. These processes are manual, labor-intensive, and rely on visual meteorological conditions (VMC) and radio-centric communication. They also rely on geographic orientation and are currently at capacity. Furthermore, these processes are standalone systems in the evolving landscape of wildland fire management, disconnected from other associated systems. Some historical context for this legacy is provided in the first part of Section 3.5.

3.5 Agency Wildland Fire Suppression-First Policies

Agency wildland fire suppression policies play a crucial role in shaping aerial firefighting needs, practices, and technological requirements. In the 20th century, the concept of “good fire” was largely replaced by public land management practices that portrayed fire in a predominantly negative light. The USFS 10 a.m. rule of 1935, which mandated the suppression of every fire by 10 a.m. the following day, exemplified this shift in national attitude away from recognizing fire as an essential and natural component of a healthy ecosystem [23]. While the USFS has since rescinded the 10 a.m. rule, there is continued pressure to quickly contain and extinguish every wildland fire as soon as possible. Among the contributing factors to this phenomenon are the ubiquitous nature of 24/7 news and video, the powerful still and video cameras readily available in smartphones, and the widespread use of social media. Wildland fires have become visible nationwide--often in real time.

In his Chief’s Letter of Intent for the 2025 Wildfire Year, the USFS Chief emphasized the need to “suppress fires as swiftly as possible [24].” The letter also committed the agency to *“using technology for fire detection and suppression such as Uncrewed Aerial Systems (UAS), satellite surveillance, cameras, tracking, and remote sensing, to increase efficiency and accuracy while reducing exposure to firefighters.”* Furthermore, the letter directed leaders from USFS National Headquarters to the Districts to eliminate any barriers that hinder resource capability or mobilization. Each of these actions underscores the significance and urgency of aviation resources in combating the escalating wildfire threat in 2025 and beyond.

3.6 Relevant Legislation, Executive Orders, Commission Reports, and Workshop Reports

Wildland fire management, specifically aviation, has been the subject of extensive past, current, and proposed legislative and policy initiatives. These include:

- Over 25 wildland fire bills are under consideration by the 119th Congress, several of which address the need for improvements in airspace management during emergency response operations such as wildland fire, including a specific bill in support of ACERO (Advanced Capabilities for Emergency Response Organization) [25].
- The Empowering Commonsense Wildfire Prevention and Response EO 14308 directs agencies to take measures to improve wildfire response through streamlined governance, improved technologies, and by reducing and eliminating bureaucratic hurdles [2].
- Two 2023 reports from a congressionally mandated Commission on Wildland Fire Mitigation and Management both discuss the need for improved airspace management in wildland fire for both current and future operations [26], [27].
- A 2023 report to the President titled, “Modernizing Wildland Firefighting to Protect Our Firefighters” addresses the need for incorporating better technology in aspects of wildland firefighting like airspace management and pointedly focuses on “critical aspects of wildfire response that are stuck—technologically and organizationally—in the last century [28].”
- A 2022 report from the NASA System-Wide Safety Wildland Firefighting Operations Workshop, cites the need for enhancing situational awareness, especially in the use of aerial assets [29].
- A 2021 report from the NASA ARMD Wildfire Management Workshop includes several findings related to the need for improved airspace management [30], [31].

3.7 Current Wildland Fire Outcomes and Trends Illustrate the Imperative

As we have discussed, there is increasing demand for more aerial firefighting aircraft with modern technologies that support safer, more effective, and efficient support for wildland firefighters. Data and trends that support this imperative include:

- On average, about 8 million acres were burned annually between 2017 and 2021—more than double the amounts observed in the late 1980s/early 1990s [32].
- From 2017–2021, USFS and DOI spent over $14B in suppressing wildland fires, with an average annual expenditure of nearly $2.9B, 21% higher than the prior 10-year average [33].
- 98% of wildland fires are contained within 24 hours of the initial response without the need of a TFR [34].
- Only 1– 2% of wildfires become large incidents, but these account for approximately 85% of total suppression costs and 95% of total acres burned each year [35].
- A 2017 report by the US Department of Commerce National Institute of Standards and Technology (NIST) estimated the annualized economic losses due to wildland fire to be between $63.5B and $285B [36].
- Aviation remains the largest single cost in wildland fire management, with the USFS 2021 Aviation Annual Report indicating over $750M expended that year [4].
- Crewed aerial firefighting aircraft are largely restricted to daytime operations under VMC. Due to smoky conditions in the morning, it is common for aircraft to wait until late morning or early afternoon to launch, constraining them to 6 – 8 hours of operations per day [37], [38]. Nighttime crewed aircraft operations are usually restricted to two National Infrared Operations (NIROPS) aircraft, or in limited cases over California or Colorado wildfires, a handful of night vision device (NVD) equipped helicopters may operate. Uncrewed aircraft (drones) have been successfully employed during both day and night DVE to map fire perimeters, detect and direct firefighters to unseen spot fires, conduct offensive aerial ignition missions, and provide timely situational awareness to ground crews and incident commanders (ICs).

4 Problem Statement: How To Improve Wildland Fire Management, Mission Effectiveness, and Safety Through Airspace Operations Management

Ground-based wildland firefighters, as previously mentioned, are the ones who ultimately contain and extinguish wildfires. Since 1930, aviation has played a significant and growing role in providing these ground firefighters with crucial remote sensing, suppression, and logistics support. Advancements in aviation technology, such as drones and federated cooperative airspace management, have offered opportunities for safer and more effective support. However, wildland fire airspace operations management has largely remained unchanged for nearly a century, depriving all wildland firefighters and the communities they protect of the full benefits these technologies promise. This ConOps aims to enhance wildland fire management safety and effectiveness through improvements in airspace operations management.

While it is true that there is a growing concern in the firefighting community of "over-suppression"—and in that sense, a perceived over-reliance of aerial assets on some fires—when aerial firefighting *is* needed, airspace operations are significantly hampered by a complex interplay of challenges that limit the effectiveness of both crewed and uncrewed aircraft. With stringent regulations designed for traditional aviation, this creates significant hurdles for seamlessly integrating emerging technologies like UAS, and limiting flight hours of crewed aircraft in DVE, rendering both *underutilized*. This creates a disconnect between the advanced capabilities of modern aviation and the actual support provided to ground firefighters and the communities they protect.

4.1 Limitations Or Gaps in Current Operations

4.1.1 Definitions

This ConOps uses two key terms, "gap" and "limitation," to identify areas of the current state to be addressed in the proposed future state.

> A ***gap*** affects a desired outcome inherently. Human-made solutions seek to reach the desired outcome despite the gap (by circumvention).
>
> A ***limitation*** affects a desired outcome through imposition. Human-made solutions reach the desired outcome within the bounds of a limitation (by conformance).

In other words, a gap is the figurative "delta" between the current and desired states, whereas limitations define the trade space in which various solutions traverse that delta. As such, all solutions aim to address a gap, and have limitations attributed to them.

The current state of wildland firefighting has many examples of both, and complex systems in this discipline often have nested, interdependent gaps and limitations—many of which exist for safety reasons. This ConOps understands that an optimal solution should take both into account holistically. New solutions must uphold and outperform previous solutions' expected safety, cost, and effectiveness. Therefore, it attempts to identify primary gaps and limitations to current and proposed solutions recognizing there may be many subsequent others.

4.1.2 Routine UAS BVLOS Operations

Since 2015, federal agencies like DOI have been authorized by the FAA to conduct BVLOS UAS flights within a TFR [39]. The first integrated UAS and crewed aircraft operation occurred in 2015 on the Paradise Fire in Washington State's Olympic National Park [40]. Since then, drones have conducted thousands of BVLOS flights in support of wildfires, often during smoky conditions that grounded traditional firefighting aircraft for multiple consecutive days [38], [41], [42]. Despite this 10-year history of successful BVLOS operations on wildfires, their adoption by ICs remains inconsistent and far from reaching their full potential [43], [44]. Often, this reluctance has been tied to the perceived inability of the current wildland fire airspace operations management system to safely integrate crewed and uncrewed aircraft in this dynamic, high-tempo mission space.

4.1.3 Degraded Visual Environments

The challenge of responding to wildfires and supporting firefighters from the air during daylight hours in DVE poses the greatest performance gap and limitation in aerial firefighting. This gap has persisted for 95 years [45]. Wildfires can ignite at any hour. A DOI assessment of wildland fire ignition times from 2015 to July 2017 found that nearly 20% of all wildland fire ignitions during that two-year period occurred outside traditional aerial firefighting operating hours [46]. Of these, 66% were discovered between the end of flight operations and midnight. This allowed those ignitions to grow uncontested by initial attack suppression aircraft for as many as 16 hours. Although federal agencies do not track statistics on the outcome of these delayed initial attack efforts, it is intuitive that a delayed initial attack would likely contribute to the growth and intensity of these fires and ultimately have an impact on the time, area, and resources required to contain these fires.

Uncrewed and optionally piloted aircraft technology for remote sensing, suppression, and logistics has been successfully tested in wildland fire scenarios covering remote sensing, suppression, and logistics [47], [48].

However, the current manual, standalone, visually dependent, radio-centric, geographically oriented, and labor-intensive wildland fire airspace management system prohibits the introduction and scaling of these DVE operations in support of firefighters and the communities they protect, perpetuating the 95-year gap.

4.1.4 Improved Safety of Traditional Firefighting Aircraft

Aerial firefighting poses several critical and high-consequence hazards, including proximity to the ground, rapid terrain changes, numerous aircraft, dynamic operations, changing and often obscured visibility, and a high sense of mission that can normalize risky behaviors. Consequently, the safety record for wildland fire aviation lags behind other government and commercial applications. Improving the safety of current crewed aircraft operations is the top priority for the desired future state of collaborative wildland fire airspace management.

4.1.5 Scalable Integrated Crewed and Uncrewed Aircraft Wildland Fire Support

The development of comprehensive solutions that address the current gaps in DVE airspace operations management and traditional aerial firefighting safety can enable routine UAS BVLOS operations. These operations will be safely and effectively integrated with crewed aircraft. This will also enable scalable, denser remote sensing, suppression, and logistic support, allowing for the mobilization of more resources to meet administrative and public expectations for swift wildfire suppression.

4.2 Confines of The Problem

To focus on areas where technology can be developed and implemented with the precision and speed demanded by current legislation, Administration priorities, and public desires, this ConOps will consider the problem to be confined to **wildland fire operations within a TFR**. These instances represent most of the large wildfires that cost the most to suppress and result in the greatest human and economic loss. Additionally, aligning with the current focus on immediate and full suppression of wildfires, this ConOps will restrict the problem to the initial and extended attack links in the integrated wildland fire system of systems. The ConOps' desired future state will also concentrate on the problem of aerial firefighting in DVE where no airspace operations management capability currently exists for remote sensing, suppression, and logistics use cases.

5 Future State

The "future state" is not a single point in time but a continuous sequence of steps where incremental improvements serve both to enhance current operations and lay the groundwork for future gains. Achieving the future state requires more than just technological advancement. Program development, training, funding approval, staffing, effective management, and "organic" user adoption are all crucial components in the journey of having the desired future state evolve continuously with minimal pushback (supported by all sides of the organizational structure). Appendix A – The Future is a Continuum describes this further.

5.1 Cooperative Airspace Operations Management

In the desired future state, the ability to improve wildfire suppression will require an airspace operations management system that can safely and effectively operate and integrate crewed and uncrewed firefighting aircraft 24/7 in all visual environments. In daytime DVE, appropriately equipped aircraft will be able to conduct suppression safely and effectively in support of active ground firefighter operations. In nighttime DVE, when ground firefighting is extremely limited due to ground firefighter safety concerns and lessons learned, aircraft equipped to handle DVE can continue to "cool" (i.e., reduce the intensity of) the fire with water (direct) suppressant operations. Due to night and day DVE periods which can be 16 –18 hours, the traditional visual airspace management practices of current wildland fire operations and reliance on the "see and avoid" responsibility of all aircraft are ill-suited to the task. Instead, the future wildland fire airspace operations management construct must be **digital** and **cooperative**, relying on appropriate federated equipment, connectivity, policies, and procedures.

There are three component levels of this digital, cooperative airspace management system:

Strategic:	Preflight route planning, area reservation and 4-D trajectory deconfliction for preflight approvals. Involves route planning, area reservation, and preflight deconfliction. It focuses on the big picture and long-term planning to ensure safe and efficient air traffic flow.
Operational:	Because "no plan survives first contact with reality," this level facilitates the timely coordination and communication of necessary inflight changes which are often made during wildland fire and other public safety and emergency response operations in reaction to these dynamic mission environments. It requires the ability for participants to make and receive approval for inflight change requests in response to dynamic mission environments and needs. It involves initiating, coordinating, and communicating necessary flight trajectory requirements.
Tactical:	Because even with careful planning and execution, unexpected situations and human deviations can arise that the strategic and operational levels are ill-equipped to handle. The tactical level represents the inner and last defense layer to ensure two aircraft do not collide. This level is all about close in, inflight coordination and collision avoidance (CCA), supported by a layered system of systems, including reliable, low latency vehicle to vehicle (V2V) communications of 4-D position and vector intent. It serves as the last line of defense, ensuring the safety of aircraft by actively monitoring and preventing potential conflicts when human/system anomalies occur.

In the desired future state, the strategic and operational levels of cooperative digital airspace management would likely be supported by systems modeled after the UTM framework, such as PAMS that NASA successfully demonstrated in flight tests in March 2025 (refer to Appendix D – NASA Testbed: Portable Airspace Management System).

5.2 Aircraft Data and Infrastructure Support Requirements

From an aircraft perspective (crewed or uncrewed), the future airspace operations management system should provide the pilot/operator with awareness of (a) the terrain, (b) the obstacles (natural and manmade such as tree snags, wires, towers, etc.), (c) other participating aircraft, (d) the target area (e.g., flame front, logistics LZ, etc.), (e) ground personnel and assets, and (f) relevant weather phenomena that may impact the mission.

As the number of aircraft able to operate in DVE increases, there will be an increasing requirement for active air traffic management to manage the growing density and complexity of air traffic safely and effectively. This will likely start with basic ground-based systems that support a few crewed and uncrewed aircraft. Then, it will build to incorporate crewed aircraft with appropriate onboard sensor, computing, and connectivity packages and resident ATGS support. Finally, it will incorporate similarly equipped long endurance drones overhead, communicating with ATGS occupying local command vehicles.

While currently deployed UTM systems incorporate support for both the strategic and operational levels of cooperative airspace management, they do not incorporate capabilities at the tactical level (close-in coordination and collision avoidance for denser air operations). At this level, the closer proximity of aircraft to each other mandates a low latency, highly reliable risk calculation and communications system. The longer it takes to make and communicate a calculation, the more conservative separation requirements become. This can impact operations and in some urban scenarios could preclude the ability of multiple aircraft to work in the same mission airspace. Likewise, any unreliability in communications with a central airspace management system node can result in a missed directive message, which can, in turn, lead to a tragic mishap. For these reasons, many have advocated a vehicle-to-vehicle (V2V) coordination and collision avoidance (C&CAS) system. This is also why the best way to facilitate the necessary tactical vehicle-to-vehicle close in coordination and collision avoidance remains an open question, not just in wildland fire, but also in discussions surrounding the FAA's beyond visual line of sight (BVLOS) notice of proposed rulemaking (NPRM). As such, future research here in the emergency response space will lend itself well across all UAM and UTM applications and will be a steppingstone for further NASA involvement. Further discussion on V2V C&CAS and its importance to fulfilling the future requirements of the tactical level of cooperative airspace management in wildland fire can be found at Appendix B.

TABLE 2 - THE ENVISIONED PROGRESSION OF WILDLAND FIRE AIRSPACE OPERATIONS MANAGEMENT IN ALL VISUAL ENVIRONMENTS

Near Term (0-2 years)	Mid-Long-Term (3-10 years)	Visionary (11-15 years)
Limited crewed and uncrewed aircraft	Increasing number of aircraft with the ATGS in an overhead sensor-compute-connectivity aircraft and a federated three-level cooperative airspace management system	Sensor-compute-connectivity long-endurance drone overhead, ATGS in a local command vehicle, fully extensile to the info-centric NAS.

5.3 A Common Operating Picture

A cooperative airspace management system requires an interface, which readers may recognize as a common operating picture (COP). This would be a timely and accurate, centralized display of all relevant situational awareness information pertaining to aerial assets and their management (along with general incident management).

Specific to the COP, the desired future state foresees a collaborative approach that has the following attributes:

- Takes advantage of the ubiquitous nature of personal smartphones to support the COP, reducing the cost and logistics challenges of providing a COP on government-issued equipment. This also enables probabilistic sampling, or crowd-sourced data collection, from the devices' own sensors.
- Leverages zero trust (ZT) cyber security methodologies to provide secure and role-based credentials to define user access level.
- Provides "emergency alert" functionality (like Amber, Severe Weather, etc. alerts) to notify firefighters of impending danger, including immediate actions to prevent entrapments and burn overs.
- Enables limited, targeted inputs to the COP from highly experienced firefighters in the field. Trained in critical areas, such as wildfire behavior, fire weather, etc., they can be a rich source of timely and valuable observations of dynamically changing conditions.
- Supports the incorporation of augmented reality (AR) features. Valuable information overlays on smartphones and tablets could provide field supervisors with critical situational awareness to the location of nearby ground and air units, values at risk, and critical infrastructure. This is especially valuable in DVE.

5.4 Use Scenarios for Integrated Airspace Management in the Future State

5.4.1 Drone-Enabled BVLOS Logistics Support

Ground firefighters require steady logistics support to sustain their efforts to contain wildfires and conduct mopup. Firefighters also need to move quickly as they build hand lines and conduct backburns (two types of fuel breaks) to protect nearby value at risk or manage fire movement. Often, arduous terrain prevents or limits how much equipment firefighters can carry on their person. Examples of such equipment are food, drinking water, radios, chainsaws, shovels, Pulaskis, mcleods, ignition torches, hose spools (hundreds of feet long), truck/generator fuel, etc. Here, aerial support can significantly aid ground crews by carrying and delivering equipment between strategic locations.

Because risk tolerance and opportunity cost prohibits crewed operations in such terrain and often smoke-occluded visual conditions, this presents a prime use case for uncrewed vehicles in the future state. Uncrewed aircraft of all sizes and configurations could accomplish such a mission at regular intervals to deliver consistent supplies to ground firefighters. An airspace management system could allow intelligent planning of these logistics missions and utilize up-to-date terrain, weather, hazard, and traffic data to ensure the flight path is both optimal and safely deconflicted, even in BVLOS operations.

Ground firefighters would have access to an interface and could monitor the progress of the logistics mission in near-real time. If conditions around the rendezvous waypoint change, crews could submit an alternative rendezvous point to the system. The system would then automatically update and deconflict the edited flight plan mid-flight, including both ingress and egress upon successful delivery. Imagine if this same process could be followed in reverse for retrieval missions, or even for an emergency extraction of an injured firefighter amid a potential burn over.

5.4.2 Night-Time Fire Suppression with Aerial Operations

As discussed in Section 4.1.3 and further described in Appendix C – Description of Degraded Visual Environments, nighttime DVE is another area where significant and immediate improvements can be made. The future state envisions the use of direct attack water instead of indirect fire retardant at night because retardant is used in conjunction with ground firefighters constructing hand lines (fuel breaks). Just like crewed aircraft, ground crews avoid night ops due to safety concerns in low visibility. However, in the future state a water drop would only require a large UAS or optionally piloted aircraft. With swarming technology, that same volume of water could be shared in many small-to-medium-sized UAS, hitting the flame front in a daisy chain-like fashion and performing temperature analysis in parallel.

Here, an airspace management system would allow geographically dispersed teams to plan missions and coordinate multiple water drops and subsequent mop-up (hot spot *and* drop evaluation) of disparate fire fronts remotely. Like the previous logistics use case, a similar workflow would enable digital information about each drone's operational intent and track data in near-real time via a robust network.

Repeating these uncrewed, direct suppression missions throughout the night and morning until DVE conditions subside would result in reduced fire intensity when ground firefighters return the following day. In theory, this daily benefit would compound over the course of the fire incident and potentially save days or weeks and prevent countless acres of fire spread.

5.4.3 Intelligent Monitoring of Fire Progression

The third main use case in the future state involves near-real time remote sensing, such as flame front detection and mapping. Whether a nascent fire or a hot spot igniting off the main burn area, using imagery sensors (all spectra) to collect situational awareness over time is critical for ICs and strategic planning. Deploying such an asset that can "see" through DVE conditions and fly BVLOS provides that much more situational awareness.

From an airspace management system, separate crews could set up an ad hoc network for digital communication, allowing them to coordinate their respective surveillance missions and cover the entire area. Here, the future state envisions robust artificial intelligence and machine learning (AI/ML) algorithms that could convert the captured imagery into fire line coordinate data. This could feed into fire-spread models utilized on scene to predict the fire's progression, help inform a common operating picture, and aid in generating more precise, yet robust, TFR geometries that could streamline FAA approval.

5.5 Future State Assumptions

This ConOps assumes a baseline increase in technical readiness level across all disciplines. Future state aerial operations would therefore make use of such advancements described below.

5.5.1 Aircraft and System Autonomy

This ConOps assumes that aircraft of all types and airspace management systems will have increasingly sophisticated self-deconfliction capabilities. Along with swarming methodologies—or more accurately, aircraft with common optimization and shared deconfliction strategies—traffic densities and operational effectiveness will significantly increase while an expected level of safety is maintained.

5.5.2 Aircraft Types

The future state attempts to remain consistent with aircraft available to the fire community today. For example, aircraft used by ATGS, SEATs, VLATs, etc. are assumed to remain in the future state. However, novel designs and improvements such as converting currently crewed helicopters into autonomous helicopters, better DVE capabilities, and more accurate and precise suppressant drop performance from both fixed-wing and rotary aircraft, are expected. Furthermore, UAS will see a significant surge in use and airframes available for various missions, from very small platforms to perhaps the scale of a VLAT, with defined FAA standards and regulations in place. Additionally, this ConOps assumes that if an aircraft exists in the future state, it can be utilized in a future state mission. Current contractual and positioning logistics for cross-jurisdictional assets is beyond the scope of this ConOps.

5.5.3 Data and Power Sophistication, Distribution

AI/ML are assumed to become commonplace in the future state. That is, statistical methods for efficient solution convergence and pattern recognition of large datasets will be paramount to precise and efficient suppression activities. Likewise, computational resources will evolve with paired/layered edge and cloud computing techniques to optimize around power and bandwidth limitations. This includes network-based approaches for shared computational resources across discrete sources, such as individual aircraft (V2V2I).

Connectivity in remote regions with lacking infrastructure is a noteworthy challenge in the path to the future state. The assumptions listed here in theory will aid in enabling such connectivity, however it will require a nontrivial investment in both physical infrastructure and data standards development beyond the scope of this ConOps.

5.5.4 Environment Mapping, Modeling

The environment around a fire has a mix of static and dynamic features: topography, weather, airspace boundaries, ground infrastructure, fire perimeter, fire fuel types, asset deployment, and other physical obstacles. The future state assumes an environment's instantaneous "state" can be detected, monitored, and updated in near-real time (tens of minutes) such that modeling may be increasingly accurate. Such a future relies on significant connectivity and bandwidth infrastructure—which, in remote areas in the United States, is perhaps one of the greatest challenges to reaching this future state. However, that is beyond the scope of this aeronautics-focused ConOps.

TABLE 3 - AIRSPACE OPERATIONS MANAGEMENT REQUIREMENTS BY VISUAL ENVIRONMENT, WILDLAND FIRE SYSTEM LINK, AND AIRCRAFT CATEGORY

	A	B	C	D	E
			Airspace operations management requirements		
	Visual environment	**Wildland fire management system link**	**Crewed aircraft**	**Uncrewed aircraft**	**Integrated crewed and uncrewed aircraft**
1	Day VMC	Initial attack - unrestricted airspace	FAA 91.113 "see and avoid" & fire traffic area (FTA) procedures. PAMS-like system provides situational awareness to ATGS.	Future FAA Part 108 BVLOS rule requirements	FAA approved UTM encompassing strategic, operational, and tactical cooperative airspace management services
2		Extended attack (TFR)*	Federated, digital wildland fire three-level cooperative airspace operations management system		
3	Night DVE	Initial attack - unrestricted airspace	NVD capable aircraft** PAMS-like system provides situational awareness to ATGS.	Future FAA Part 108 BVLOS rule requirements	FAA approved UTM encompassing strategic, operational, and tactical cooperative airspace management services
4		Extended attack (TFR)*	NVD capable aircraft** federated, digital wildland fire three-level cooperative airspace operations management system	Federated, digital wildland fire three-level cooperative airspace operations management system	NVD capable aircraft** federated, digital wildland fire three-level cooperative airspace operations management system
5	Day DVE	Initial attack - unrestricted airspace	N/A***	Future FAA Part 108 BVLOS rule requirements	N/A***
6		Extended attack (TFR)*		Federated, digital wildland fire three-level cooperative airspace operations management system	

*Includes crewed and uncrewed aircraft operations in support of prescribed burns.

**NVD capable aircraft comprise less than 10% of all firefighting aircraft and are predominantly in and managed by state and local government agencies in California.

***NVDs are inoperative during the day, regardless of visual environmental conditions. Optionally piloted helicopters (OPH) operated remotely have successfully demonstrated the ability to conduct wildland fire suppression and logistics flights in day DVEs (2014, 2015 KMAX flight demos). This capability alleviates the requirement to equip crewed-only aerial firefighting aircraft with the necessary synthetic vision and associated systems for crewed day DVE operations and removes the human risk from this hazardous flight environment.

- Planned expansion of currently limited capability
- FAA planned near-term implementation
- NASA ConOps' visionary future state
- FAA planned far-term implementation
- No plans to address gap due to safety concerns

For detailed descriptions of each section of Table 3, refer to Appendix B.

6 Conclusion

Aerial operations is a primary target for NASA Aeronautics to direct its expertise and research to in the broader, nation-wide effort of improving the effectiveness of wildland fire management in the 21st century. In collaboration with the FAA and wildland firefighting stakeholders, this ConOps outlines ways to improve the safety of crewed aerial firefighting aircraft and integrate uncrewed aircraft which can safely operate in arduous and degraded visual environments (DVE) continuously for extended periods of time (24/7). However, doing so requires a corresponding increase in airspace management capabilities such that crewed aircraft safety is not compromised and is in fact bolstered. While such environments in remote regions can present a challenge due to a lack of infrastructure, they present an opportunity for innovation of agile and scalable solutions without burdening existing systems. For mixed crewed and uncrewed aircraft, a TFR around a fire traffic area is the ideal proving ground for new air traffic management methodologies given the risk-reward tradeoff of an emergency aid scenario. To address strategic, operational, and tactical needs, a cooperative airspace management system could enable enhanced planning and deconfliction for remote sensing, logistics, and suppression during aerial firefighting missions.

Appendix A – The Future is a Continuum

A-1: Near-Term, Mid-Term, Long-Term, and Visionary Waypoints

One of the key assumptions in addressing the desired future state of wildland fire is that the future is not a single point in time, but a continuum. Progress towards the desired future state will occur across a series of waypoints that enable iterative improvements and adoption. Waypoints along this continuum are not merely defined by technology readiness levels (TRL). Government funding levels, realities of budget cycle constraints, staffing, program, organizational culture, and policy considerations also play a role in defining what can be accomplished at each waypoint and the successful implementation of any proposed technology along the continuum. ConOps that neglect to consider the full range and dependencies of these considerations often fail to reach their desired future state. For planning purposes, it is useful to define the four phases: Near-Term, Mid-Term, Long-Term, and Visionary (Figure 3). This ConOps describes the desired future state to occur in the Visionary (11-15 year) milestone.

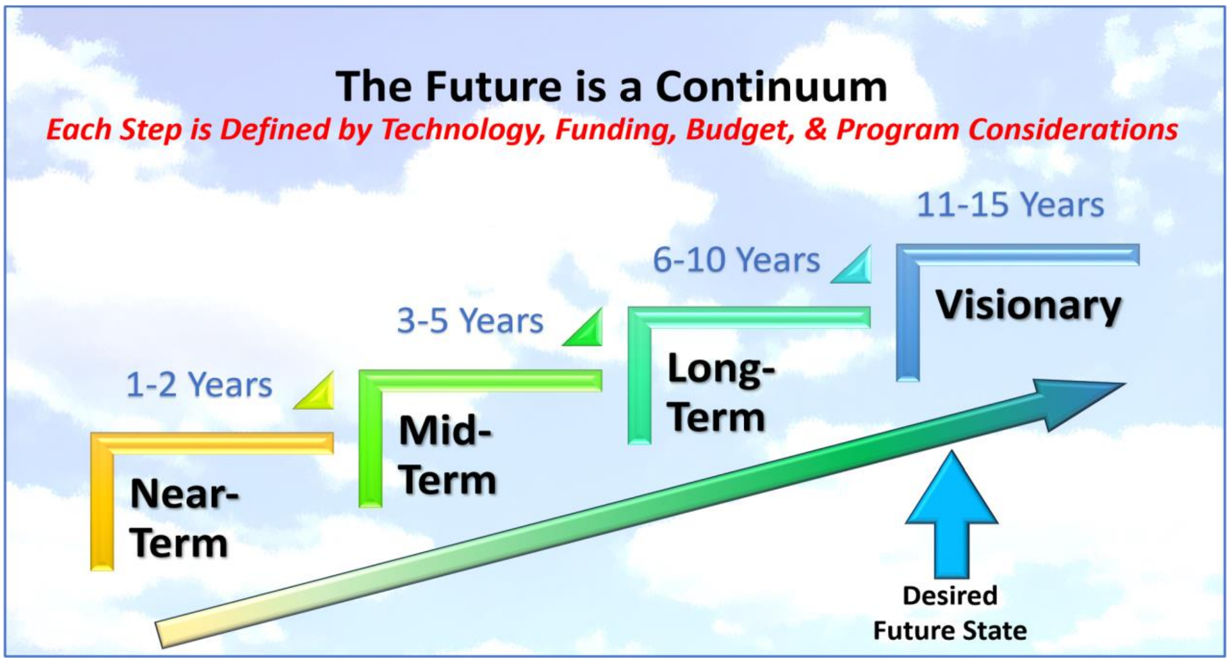

Figure 3 - The future is a continuum. The desired future state is focused on the visionary milestone.

A-1.1: Near-Term: 1-2 Years

In this stage, technology is field ready, does not require additional agency funding, requires little to no training, and is generally accepted by the workforce as immediately necessary and ready for use in a prudent, phased approach.

- Technology is mature and fielded in other industries/use cases. TRL 7-9.
- Technology needs little to no customization to meet wildland fire requirements for a minimally viable product (MVP).
- Costs are within constraints of current wildland fire agency budgets.
- Little to no additional integration and training is required.
- The subject mission set is part of a risk-reduction strategy.

A-1.2: Mid-Term: 3-5 Years

- Technology system has been demonstrated in a relevant mission environment (not necessarily the one for which it is ultimately intended) but has not been fielded in other industries/use cases; TRL 6.
- MVP requires customization to meet wildland fire requirements.
- New technologies align with current agency strategic plans and can be tied to specific ongoing and/or future initiatives outlined in these documents and/or current programs. Implementation and management fit within the existing agency/interagency wildland fire organizational structure, but would likely require additional staffing resources, including new skill sets/background.
- Available current budget/appropriation funding is insufficient to support completing necessary development, testing, and fielding. Additional funding requires either agency budget reprogramming or Congressional appropriation action.

A-1.3: Long-Term: 6-10 Years

- Technology component(s) have been validated in a laboratory environment and in an industry-relevant use case environment, but not specifically for the intended wildland fire mission. TRL 4-5.
- Identification and integration of wildland fire requirements is required to influence the current and future direction of this technology development.
- Applications for this technology are largely beyond the concepts currently expressed in agency strategic plans, programs, and funding initiatives. Requires additional strategic and program planning.
- Research, development, developmental and operational testing, and field integration funding for this technology are not currently included in agency budgets/plans. Requires new/additional appropriations.

A-1.4: Visionary: 11-15 Years (The Desired Future State Timeframe)

- Basic principles underlying this technology have been observed and reported. Initial work on the technology concept and the potential wildland fire application has been conducted, and an experimental critical function and proof of concept have been identified as part of TRL 1-3.
- Potential alignment and integration with the wildland fire mission are unclear and in early formulation. The potential cost and time to research, develop, test, evaluate, and field this technology in the wildland fire mission is unknown.
- Current agency strategic plans and programs do not mention this technology and its potential applications. There is no current wildland fire agency funding for research, development, and testing of this technology.

Appendix B – Detailed Discussion of Table 3

To prioritize and sequence the steps necessary to realize the desired future state of wildland fire airspace operations management, it is helpful to categorize them based on a combination of the required technological and policy challenges and the likely safety and mission enhancement return of each. For the following sub-sections, please refer to Table 3 on page 16.

B-1: Initial Attack in Daytime VMC Conditions (No TFR, Row #1)

As historical data suggests, initial attacks are typically conducted without the benefit of a TFR. Without a TFR, operations take place in unrestricted airspace, subject to Federal Aviation Regulations (FARs) and standard FAA airspace management rules and practices. Crewed aircraft operate under VFR, see and avoid principles, and adhere to FTA procedures. Uncrewed aircraft operating alone in this daytime VMC initial attack scenario require a BVLOS waiver from the FAA or will meet the requirements of future uncrewed aircraft BVLOS rule (i.e. Part 108 [49]).

Within this context, imagine a future state daytime VMC environment where crewed and uncrewed aircraft conduct joint initial attack operations. In this case, the preflight planning, the safe ingress and egress between the wildfire location and a ground base, and the dynamic operations encompass all three cooperative airspace management level services (strategic, operational, tactical). Operations in this visual environment would require an FAA-approved UTM system.

B-2: Extended Attack in Daytime VMC Conditions (TFR in place, Row #2)

In contrast, this scenario assumes a TFR *is* established to ensure the safety of ground firefighters, participating aircraft, and nonparticipating aircraft during dynamic, high-tempo wildland fire suppression operations. As operational control of airspace within a TFR is granted to the wildfire IC, airspace operations management within the TFR falls under the responsibility of the IC and their designated representatives (e.g., ATGS).

In the desired future state in this scenario, a federated, digital wildland fire cooperative airspace operations management system that encompasses and integrates all three levels (Strategic, Operational, Tactical) would provide the following benefits:

Collision avoidance and mitigation for all aircraft

- **Strategic** preflight planning and route/area deconfliction and approval.
- **Operational** coordination, deconfliction, and communication of necessary inflight trajectory/area requirements.
- **Tactical** in close C&CAS operations that leverage reliable, low latency broadcast V2V communications of position and velocity vector that support determination and transmission of proximity and potential conflict awareness, suggested corrective actions, or directed avoidance maneuvers. Participating aircraft, historically, represent the highest source of near-misses and midair collisions in wildland fire operations, and mitigating this risk promises a significant return on investment.

CFIT avoidance and mitigation for crewed aircraft

- Wildland fire aircraft mishap data has shown that CFIT is a significant causal factor in aircraft accidents and fatalities.
- By providing pilots and aircraft systems with terrain data through the cooperative airspace operations management system, the risk of CFIT can be mitigated.

Expanded UAS BVLOS operations

- Although UAS BVLOS flights in a TFR have been authorized by the FAA for wildland fire agencies since 2015, the manual process for coordinating, managing, and monitoring these flights has failed to build the level of trust among firefighters necessary to support consistent adoption for all wildfires.
- The implementation of an integrated three-level wildland fire airspace operations management system would enhance the trust level among ICs and ATGS, enabling increased UAS BVLOS operations.

Integrated crewed and uncrewed aircraft operations

- As the wildfire threat has continued to increase and the government and public outcry for quicker suppression of these fires has grown as a result, the ability to safely and effectively facilitate more concentrated aviation support becomes more pressing.

Scalable and more concentrated aerial remote sensing, suppression, and logistics support to firefighters

- While the strategic and operational levels of a cooperative airspace management system support the integration of crewed and uncrewed aircraft in wildfire, it is the capabilities and limitations of the tactical level that will determine the degree of aircraft concentration that can be achieved. As an example, tactical level C&CAS systems that rely on communication and coordination through a central airspace operations management system will require greater separation between aircraft than one that leverages direct, reliable, and low latency V2V communications between aircraft in proximity to each other.

B-3: Initial Attack in Nighttime DVE (No TFR, Row #3)

Like daytime VMC, nighttime DVE initial attack is conducted in unrestricted airspace with no TFR in place. Accordingly, responding crewed and uncrewed aircraft will be subject to FARs and requirements for transiting to and operating within the FTA. Crewed suppression and logistics aircraft must be NVD-capable and crewed with NVD-trained and proficient pilots to perform these low altitude missions. Crewed remote sensing aircraft could be positioned at altitudes that would preclude the need for NVDs.

Independent, uncrewed aircraft would be required to comply with FAA BVLOS waivers or future requirements for Part 108. Integrated crewed and uncrewed aircraft operations in nighttime DVE outside a TFR would require an FAA-approved, UTM-like system (such as the PAMS case solution presented in this ConOps) that encompasses strategic, operational, and tactical level airspace operations management.

B-4: Extended Attack in Nighttime DVE (TFR in place, Row #4)

As in the daytime VMC extended attack B-2 scenario, the presence of a TFR provides increased opportunities for the employment of uncrewed aircraft and the integration of crewed and uncrewed aircraft in the remote sensing, suppression, and logistics use cases. Crewed aircraft engaged in suppression and logistics support missions in daytime VMC will require NVD capabilities. *Caveat:* crewed aircraft cannot be used in cases where the smoke from the mature wildfire so severely obscures visibility as to make the NVDs unusable.

Supporting uncrewed aircraft will require a federated, digital, wildland-fire-compatible, three-level airspace operations management system to facilitate BVLOS flight deconfliction, coordination, and collision avoidance. Likewise, integrating NVD-capable crewed aircraft and their uncrewed counterparts will require a more mature version of this system that is able to handle increased numbers of aircraft.

B-5: Initial Attack in Daytime DVE (No TFR, Row #5)

As with the previous B-1 initial attack operations, those in daytime DVE are assumed to be conducted in unrestricted airspace and subject to FARs. However, in this instance, the DVE preclude the crewed aircraft from operating under visual flight rules, and NVDs do not apply. Given these facts and the absence of ongoing efforts to develop and equip crewed aerial firefighting aircraft with sensors, synthetic vision, and other systems that would enable them to operate in daytime DVE safely and effectively, aerial assets are considered unavailable in daytime DVE.

As during the daytime VMC and nighttime DVE initial attacks, uncrewed aircraft would be subject to FAA waivers or compliance with the future Part 108 rule to conduct BVLOS operations.

B-6: Extended Attack in Daytime DVE (TFR in place, Row #6)

Extended attack in daytime DVE is a common practice when fighting evolved wildfires which often precludes critical aerial support to firefighters on the ground for multiple hours each day, occasionally for the entire day, and sometimes for multiple days on end. The lack of technology that could enable crewed aircraft to safely and effectively carry out suppression and logistics missions in DVEs precludes their use for this scenario, either alone, or in conjunction with uncrewed aircraft. Appropriately equipped crewed aircraft flown above the DVE could possibly be used in a remote sensing role.

Coordination of uncrewed BVLOS operations in this scenario would be accomplished through the same federated system of digital wildland fire cooperative airspace operations management that would support extended attack UAS operations and integration with crewed aircraft in both daytime VMC and nighttime DVE.

B-7: Solution Focus

Based on the previous segmentation analysis, the solution will focus on the confluence of these factors:

1. Temporary Flight Restrictions (TFR)
2. Extended Attack (EA)
3. Daytime VMC, Nighttime DVE, Daytime DVE.

The solutions developed will prioritize:

- 24/7 aerial remote sensing, suppression, and logistics support to firefighters and the communities they protect
- Enhanced crewed aircraft safety (near misses, midair collisions, CFIT)
- Uncrewed aircraft BVLOS
- Integrated and scaled crewed and uncrewed aircraft operations.

Appendix C – Description of Degraded Visual Environments

C-1: Overview

This ConOps posits that increasing the capabilities of aerial assets to safely operate in DVE would have a profoundly positive impact on suppression efforts and fire management. In support of this core thesis, this appendix defines a DVE in detail.

Separate from a pilot's vision health, which is routinely checked to possess a pilot's license, a DVE involves the physical way light interacts with external objects—through absorption, refraction, diffraction, transmission, and scattering. Practically, these interactions manifest as four kinds of DVE: illumination, occlusion, contrast, and relative size. Because the focus in this discussion is safe flight operations, illumination and occlusion are most critical to address to maximize flight time (i.e., these conditions lead to grounding aircraft).

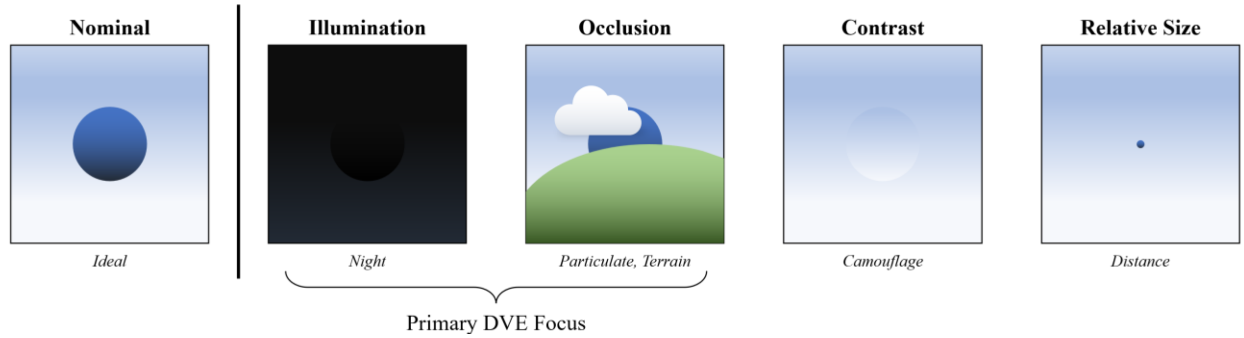

Figure 4 - Physical conditions that cause a DVE.

Different lighting and angles can dramatically change how an object is perceived. For a pilot operating under VMC and maintaining visual separation with other aircraft, it is not an exaggeration to say their life depends on these conditions remaining fair. Not only is it standard protocol to not fly in already poor conditions, but missions will also be grounded if the conditions are forecasted to degrade, even for just a fraction of the time. In the current state, this is one area with zero risk tolerance for the safety of personnel.

This appendix aims to convey how frequent aerial firefighting assets are prevented from participating on a fire. DVEs encompass more than just the nighttime; the fire's own smoke will often make conditions unsafe during the day, and current solutions such as night vision devices are less effective than the layperson may realize. Further, aerial operations enable safer and more effective ground operations by reducing fire intensity. In other words, grounding aircraft not only loses the immediate benefit of a reduced response, but their absence also sets ground operations back—a compounding challenge, especially on a large fire.

C-2: DVE Focus

C-2.1: Inversions and Smoke

An atmospheric inversion, or temperature inversion, is a key contributor to daytime DVE. Under nominal conditions, ambient temperature gradually cools with altitude; but an inversion means a layer of warmer, less dense air rests on top of cool, dense air (i.e., the layers are inverted) [50]. As aviators are concerned, this occurs in low altitudes (hundreds or low thousands of feet AGL (above ground level), but that is enough to create a DVE scenario. In this case, the warmer layer acts as a ceiling trapping a fire's smoke, which begins to spread outward rather than up. The smoke blankets a much larger swath of land compared to the fire's burn area.

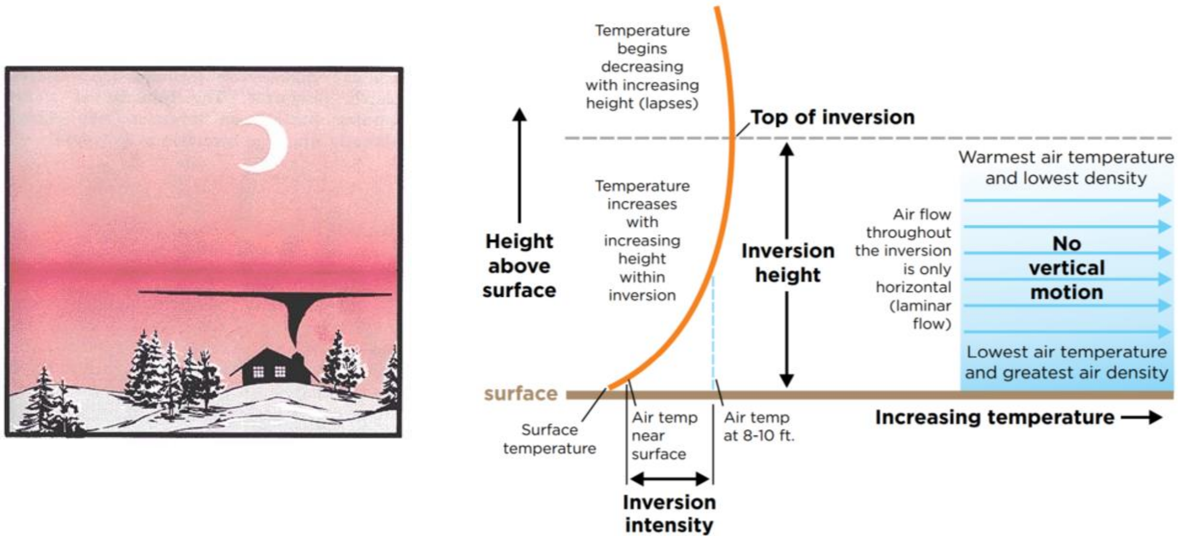

Figure 5 - (Left) Temperature inversion pictogram, PMS 425 1-2 [51]. (Right) Temperature inversion profile [50].

The key indicators that an inversion may form are calm conditions, clear skies, low surface temperatures, and high surface air density. Conversely, the main antidote to an inversion is the sun warming the Earth's surface and inducing wind in the later parts of the day to mix and "reset" the layers of air. Because of this, it is common for an inversion to start at night and carry into the following morning.

Even if VMC conditions exist at cruise, key mission objectives may be shrouded by the settled smoke, making it difficult or impossible to see terrain and ground fire fighters (occlusion). Retardant and water drops, which can occur as low as 100-feet AGL, are highly dynamic maneuvers and are unsafe to perform in instrument meteorological conditions (IMC) even if the pilot is instrument certified. As such, inversions typically ground crewed aircraft operations entirely.

C-2.2: Low Light and Shortcomings in Night Vision Devices

The more obvious DVE is during nighttime when visibility is minimal from a lack of illumination. Recall that once inside an FTA, all aircraft are under control of the ATGS and fly visually without autopilot. Between arduous terrain and other aircraft, this is too risky at night. Speakers at the 2024 Aerial Firefighting: North America Conference estimated that less than one percent of all firefighting aircraft nationwide are NVD capable, due to several reasons: 1) NVDs are less effective than shown in pop culture, 2) the training required to fly effectively with NVDs is extensive and expensive, 3) low-altitude, night VFR flight remains a highly risky exercise because of the macro-level reduction of situational awareness, regardless of the first two reasons. If one aircraft has NVDs, that does not guarantee another will; and firefighters aim to protect life (including pilots' lives), property, and environment, in that order.

NVDs work by amplifying light. In a space devoid of all light, NVDs are ineffective. Of course, there is some light from stars, distant light pollution, and perhaps a few structures with lights. Ironically, in firefighting, NVDs see the worst of both extremes: remote areas with minimal light, interspersed with patches of extreme brightness from the fire front. In fact, the small fraction of aircraft that do have NVDs are likely in regions where a large amount of light pollution allows for practical use. Combine these factors with the reduced visual contrast and small field of view, it is clear that NVDs are a means to an end rather than a full solution to nighttime DVE.

C-3: Importance to Fire Missions

C-3.1: Symbiosis Between Aerial and Ground Assets

A common question encountered in this research is if ground assets can remain effective or even substitute for aerial assets in times of DVEs. It is a good question, because ground assets today provide much of the labor to contain a fire through hand lines and back burns. However, the relationship between aerial and ground assets are symbiotic—they both contribute to the suppression effort in meaningful and different ways that support each other. For example, retardant slows a flame front. It is always dropped between the flame front and the ground crews to buy critical time to complete a hand line and egress to safety before the fire reaches their location. The potential benefits of delivering substantial amounts of water directly onto the fire during these extended daily DVE periods have also been widely recognized [52], [53].

The ATGS and other aerial surveillance aircraft also provide critical situational awareness to ground assets. This aids in strategic maneuvering and emergency extraction if ground assets find themselves in a dangerous situation. In remote regions with limited connectivity, this service is invaluable. A newer use case for aerial reconnaissance is to assist in mop-up, which confirms if the entire perimeter of the fire is cool enough to not re-ignite. Historically, this was a fully manual process with ground crews taking significant portions of their shifts to walk the perimeter. Today this can be done in a fraction of the time with an aerial IR camera and frees ground crews to either continue suppression efforts, help bystanders, or even begin the recovery effort.

C-3.2: Temporal Expansion of the Mission Envelope

According to a report, "Aerial Fire Fighting Operational Statistics (2024): Very Large/Large Air Tankers," and depicted in Figure 6, over 80% of retardant drop flights departed after 12:00 p.m. [54]. This data underscores the substantial portion of each 24-hour operational period (16 - 18 hours) when wildfires burn and potentially expand uncontested due to the absence of aerial suppression.

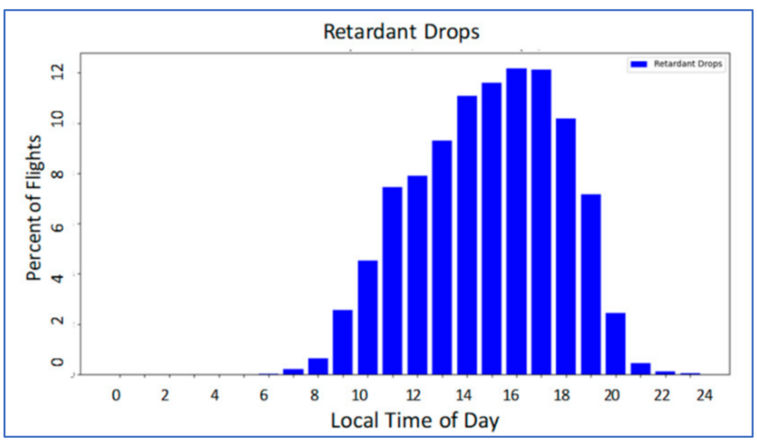

Figure 6 - Retardant drop aircraft departure times - Aerial Fire Fighting Operational Statistics (2024) Very Large/Large Air Tankers, by Lance Sherry and Mandar Chaudhari.

Figure 7 shows a 24-hour cycle with approximate intensity-time curves for the various factors relevant to this DVE discussion. Between inversions and nighttime, the average window in which crewed aircraft today can safely perform their missions is limited to just 30% of a 24-hour cycle during the afternoon (green) which happens to coincide with the most intense fire behavior. Not only could a solution to DVE expand this by almost 250% to the full 24-hours, but the return would be exponential because aerial assets could be deployed continuously, including during times of low fire intensity and resting ground crews. Over the span of a fire incident, each day could theoretically start from a more manageable position than if aerial assets were grounded.

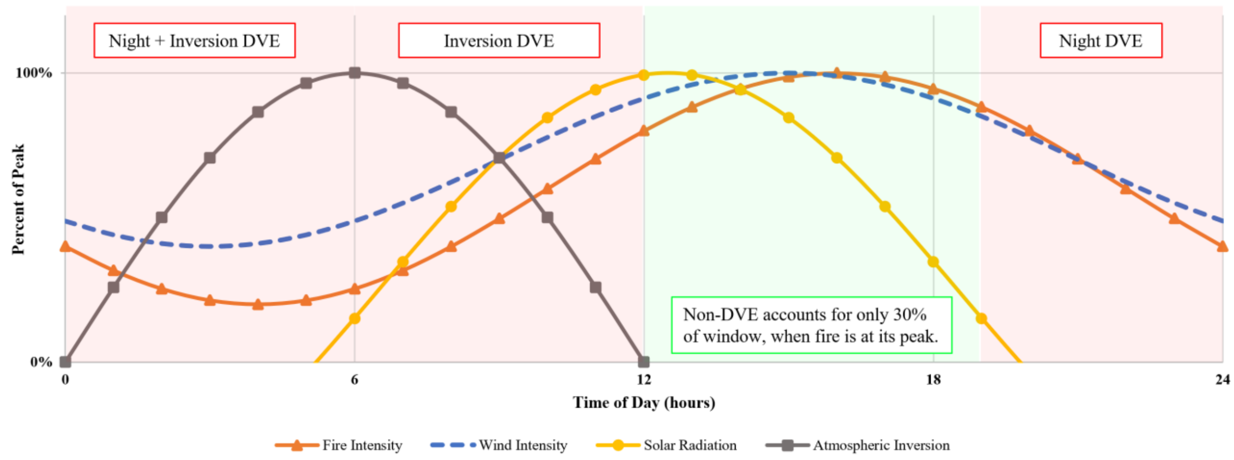

Figure 7 - A representative 24-hour DVE cycle.

C-4: Relation to BVLOS

There is similarity between the terms DVE and BVLOS, in that both involve visual obstruction (or obscuration) and an aircraft. The difference lies in the point of view from which that visual obstruction/obscuration occurs. DVE is always from the perspective of an airborne aircraft to a subject (the ground, other air traffic, or any external mission objectives). BVLOS is always from an operator to the airborne aircraft they control. Note, this says nothing about if the aircraft is crewed or uncrewed, or where the operator sits. It is a subtle distinction, and Figure 8 below shows this directionality. In conjunction with new BVLOS rules, UAS and their operators will have the opportunity to fill the gaps created by DVE. This ConOps envisions the future of fire incidents operating in mixed environments in every way: crewed, uncrewed, BVLOS, DVE, and clear skies.

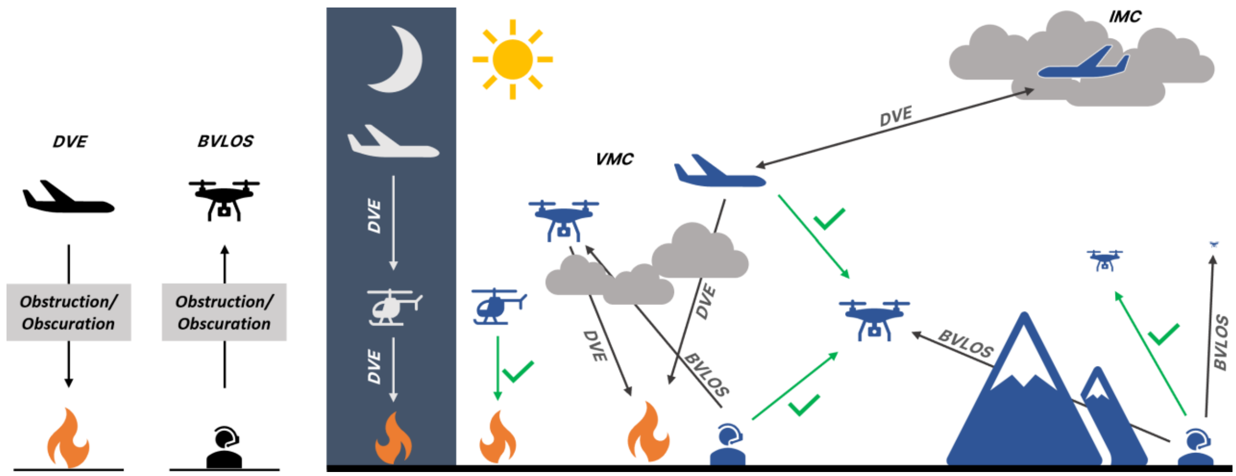

Figure 8 - Directionality of DVE versus BVLOS.

Appendix D – NASA Testbed: Portable Airspace Management System

This section describes NASA's testbed for an early-stage wildland-fire-specific UTM system. This is presented as a view into NASA's current research, including data collection and iteration, in the path towards the desired future state. This portable airspace management system (PAMS) addresses the first level, strategic, of the three-level cooperative airspace operations management system described in Section 5.1. Later versions of the PAMS will include the operational and tactical levels in future technology transfers. In other words, what is described here will not be *the* future state solution, but rather an initial phase and inspiration for eventual market-available systems.

D-1: High-Level System Architecture

The purpose of the PAMS is to enable safe, continuous, 24-hour aerial firefighting operations in all environments and phases of a fire response, including mixed crewed and uncrewed aerial operations. To serve its purpose, PAMS must provide capabilities for advising flyable trajectories that are hazard-free, clear of obstacles, and deconflicted from other aerial vehicles. These capabilities will rely on key data services that enable a common operating picture. PAMS must also support effective coordination between ground and air operations to prevent unintended harm to personnel or damage to ground assets, for example, avoiding injury or destruction during water or retardant drops. In addition, the PAMS system should support all aerial firefighting personnel, including—but not limited to—ATGS, UAS operators, and crewed aircraft pilots.

Figure 9 illustrates the high-level system architecture of PAMS as a federated network consisting of multiple Wildland Fire Service Suppliers (WFSS) and Supplemental Data Services. Like Uncrewed Aircraft System Service Suppliers (USS), WFSSs collaborate to share information, deconflict airspace, and coordinate aerial operations. All these functions leverage supplemental data to enhance safety and operational efficiency.

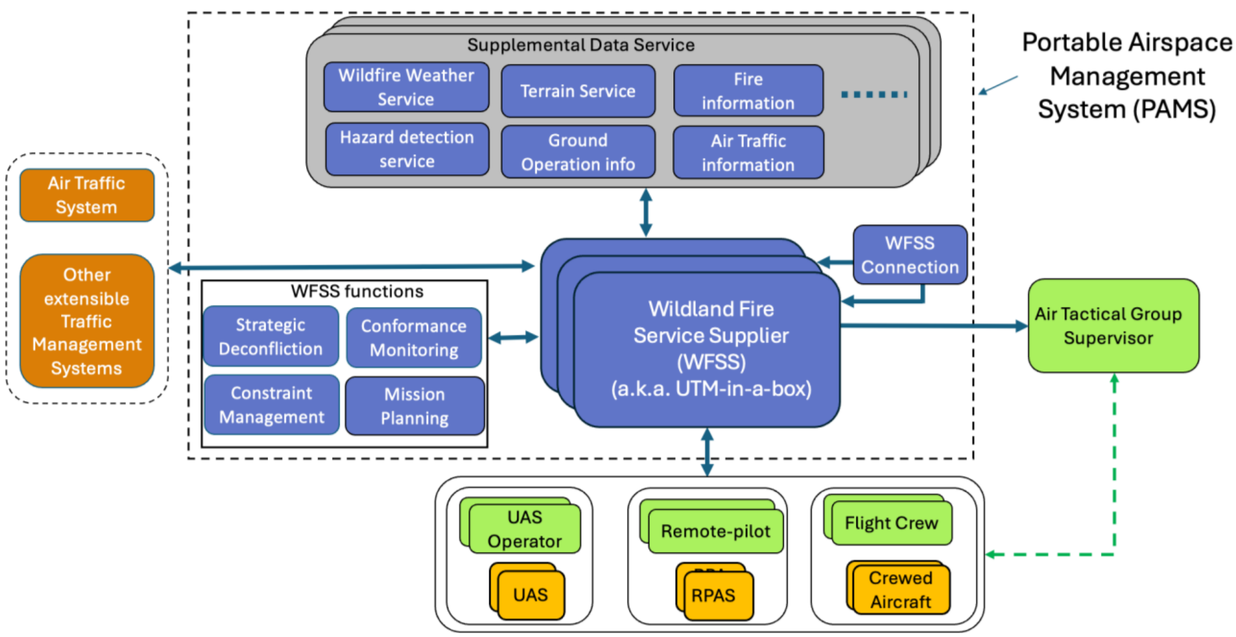

Figure 9 - PAMS high-level system architecture.

D-1.1: Wildland Fire Service Supplier

The initial WFSS builds upon the American Society for Testing and Materials (ASTM) standards for USS specifications that are part of the UTM constructs. It includes core airspace management functions such as strategic deconfliction, conformance monitoring, and constraint management. It also incorporates mission planning functions that enable safe, efficient, and coordinated flight planning in DVE.

While the WFSS was built upon the minimally necessary capabilities defined for USS, its designers specifically adapted features to meet the unique demands of wildfire aerial operations:

1. Ability to deploy to field (portability) in dynamic incidents
2. Robustness for varying degrees of network connectivity
3. Support for alternative methods of strategic deconfliction that are suited to mixed-operations environments and varying communication conditions

One of the major challenges in wildfire aerial operations is the varying performance of different communication methods. To address this challenge, commercial, off-the-shelf (COTS) communication devices will form local radio networks with aerial relay to satellite-based communication. The term “WFSS connection” distinguishes this effort from that of USS., Development of robust WFSS airspace management functions to perform in variable network conditions remains as another challenge.

D-1.2: Supplemental Data Service

Wildfire aerial operations occur in highly dynamic environments characterized by shifting terrain, changing wind conditions, evolving fire behavior, turbulence, and real-time updates to ground and hazard information. To ensure safety, each flight path must stay within the aircraft’s performance envelope (including speed, acceleration, and climb/descent rates), account for environmental factors such as wind and weather, and avoid known hazards. Integrated access to the required information is part of PAMS’ design and is crucial to the mission planning capabilities provided by PAMS.

Moreover, close coordination with ground operations is essential to preventing unintended harm to personnel and damage to critical infrastructure. As drones are more widely used to collect real-time data in these settings, a key challenge moving forward is how to process and integrate this data efficiently to support scalable and effective airspace management.

D-1.3: Interactions Between PAMS and External Traffic Management System

While PAMS is primarily focused on managing aerial operations within the TFR area, it must also support the integration of flights entering and exiting the TFR. This includes providing essential information to external traffic management systems and minimizing disruptions to their operations to ensure seamless transit for aircraft.

D-1.4: Participants: Roles and Responsibilities

PAMS is designed to support various roles involved in wildfire aerial operations by enabling effective coordination and situational awareness. As such, it provides role-specific and role-based airspace and data access (such as other users’ states and intents) with interfaces, role functions, and other capabilities tailored to the unique needs of each user group. These roles and capabilities, summarized in Table 4, are dependent on a combination of visual environment, aircraft type, and airspace category factors and assume extended attack within an established TFR. However, in initial attack scenarios where a TFR has not been established and aircraft are operating under visual flight rules (VFR) under the management of an ATGS in the fire traffic area (FTA), a similar system can provide valuable situational awareness to the ATGS and participating aircraft.

TABLE 4 - PROPOSED ROLES IN THE PAMS WORKFLOW

User group and role	Corresponding PAMS Capability	Supporting PAMS Information and Services
Air Tactical Group Supervisors (ATGS)	Ground-based situational awareness and air traffic coordination in DVE.	All information, functions, and advisories required to support safe and efficient mixed operations in complex and dynamic settings.
Operators and Pilots of Crewed and Uncrewed Drones	Safe and informed flight planning; Communication with other pilots and operators; integration with ground operations.	Relevant environmental data and surrounding air traffic information in tools for ATGS coordination.

D-2: PAMS Development Approach

The development and testing of PAMS are structured into four sequential Technical Capability Levels (TCLs), as illustrated in Figure 10. Each TCL incrementally develops and evaluates certain critical capabilities required to meet the overall system goal. The following sections provide a more detailed description for each TCL.

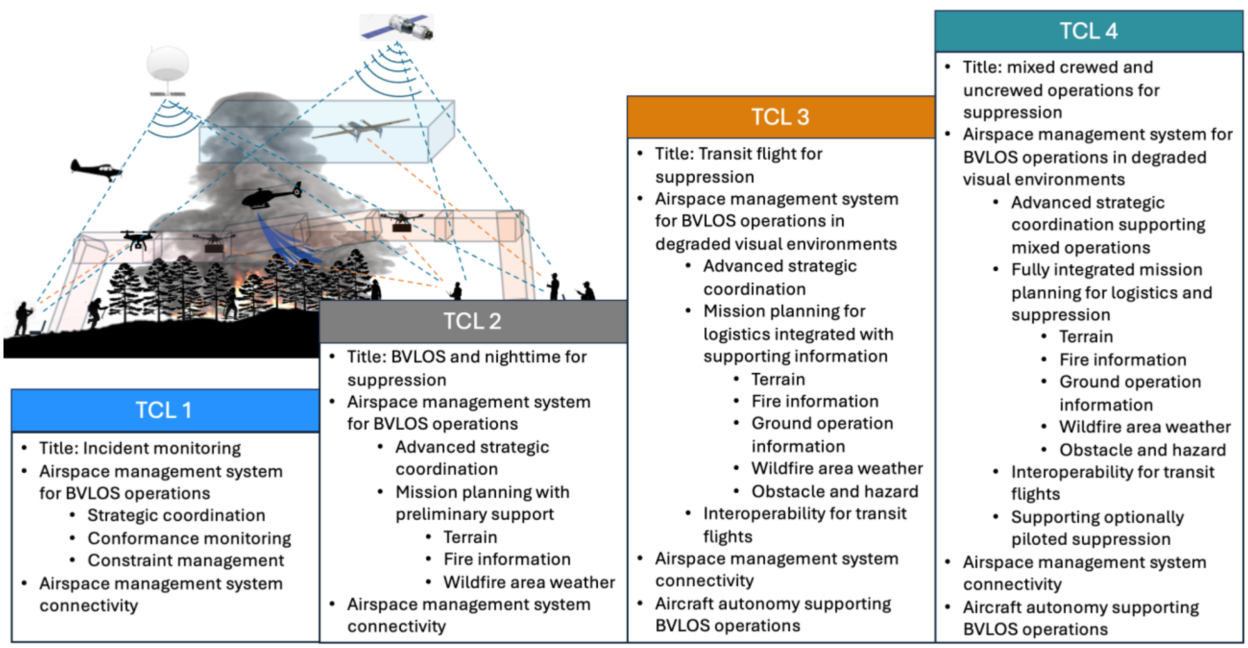

Figure 10 - PAMS development and testing progress.

D-2.1: TCL 1, Baseline Capability and Field Validation

In TCL 1, the baseline PAMS system was developed with core airspace management functionalities under a federated management framework with multiple PAMS nodes. Each PAMS node was equipped with three basic airspace management functions: strategic (volume-based) coordination, proactive constraint management, and reactive conformance monitoring. A local radio mesh network, supported by a drone acting as an airborne communication relay, was deployed to enable inter-node connectivity within the wildfire environment.

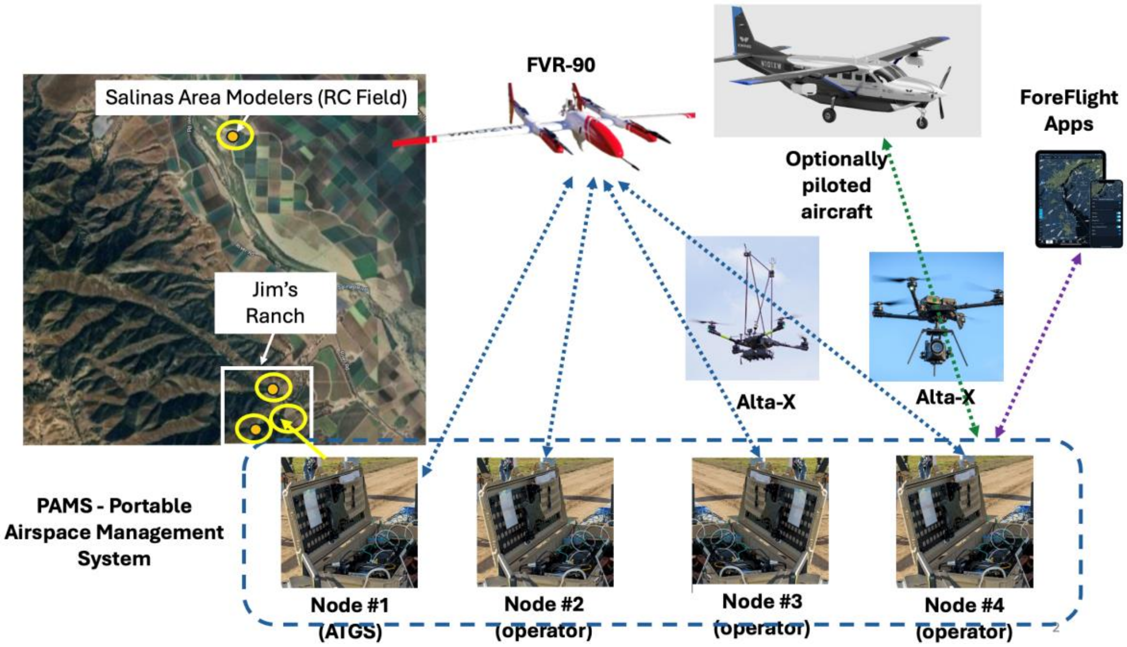

Figure 11 - PAMS supporting multi-vehicle coordination in ACERO's field test.

Field testing for TCL 1 took place in March 2025 near Salinas, California. PAMS successfully managed the coordination of concurrent operations of four aerial vehicles, including both Type 1 and Type 3 drones, as well as an optionally piloted aircraft. The system demonstrated the ability to share and coordinate flight operational plans across platforms, demonstrating its effectiveness in managing complex, multi-vehicle operations in mountainous terrain. Test partners included AirSpace Integration, Overwatch Aero, the U.S. Department of the Interior, CAL FIRE, and Joby Aviation [55].

D-2.2: TCL 2-4, Progressive Capability Enhancements

TCL 2 through 4 represent critical developmental milestones in advancing PAMS toward full operational capability for supporting continuous, 24-hour aerial wildfire suppression missions. NASA hopes to conduct these tests in FY 26 – 29.

D-2.2.1: TCL 2

TCL 2 will focus on enabling safe BVLOS and nighttime operations. This phase introduces new capabilities that incorporate key environmental factors—such as wildfire-specific terrain and dynamic weather conditions—into safe flight planning and airspace management. While terrain and weather data are essential even in urban drone operation (e.g., package delivery), their integration into wildland firefighting faces the unique challenge of a highly dynamic and unpredictable operational environment.

D-2.2.2: TCL 3

TCL 3 will address safe and scalable transit flights into and out of TFR zones. The main challenge will be to reconcile different flight intent-sharing paradigms. Conventional aircraft rely on structured flight plans, but UAS typically share intent via operational volumes—pre-defined polygons defining the confines of operation which are liberally defined to maintain conservative safety margins. Identifying the essential information that must be exchanged between the PAMS-managed TFR traffic and external airspace systems is a necessary first step—but not sufficient on its own. To achieve full integration, advanced strategic coordination capabilities must be developed to seamlessly manage conflict detection and resolution for transit flights.

D-2.2.3: TCL 4

TCL 4 will focus on mixed operations involving both crewed and uncrewed aircraft. Building on the capabilities developed in TCL 3, this phase will emphasize situational awareness and airspace coordination tools for crewed aircraft pilots. Specifically, PAMS will provide real-time information, including drone positions, velocities, and operational intents, through onboard systems. More importantly, PAMS will enable effective coordination between crewed and uncrewed systems operating in shared, complex airspace.

D-3: Phased Technology Transfer Plan: System Specs, Documentation, Requirements

NASA's objective in developing a portable airspace management system testbed is to demonstrate safely enabled use of drone operations (of all sizes) throughout all visibility conditions for wildland fire management. Critical use cases that benefit from use of drones include monitoring, suppression (particularly in DVE), and logistics support. Continuous monitoring of wildfires by drones allows assessment of which resources, and at which locations, are needed to manage fires. Aerial suppression supports the firefighters on the ground by taking on some of their workload. Logistics support by drones, whether autonomous or remotely operated, allows for dispatch of equipment, such as hoses and axes, and enables delivery to easily accessible locations without the need to transport by ground.

One fundamental technology transfer partner for portable airspace management is the FAA. Section 910 of the FAA's reauthorization (2024) states clearly that the FAA will work with NASA and with members of the wildland fire community to establish guidelines and rules for usage of drones for wildfire management. Once the FAA provides recommendations for use of drones, particularly for BVLOS, the broader aerial wildfire stakeholders will benefit. A key aspect of BVLOS implementation is UTM services. The FAA, NASA, and industry partners have demonstrated the success of these services at key site operations in Dallas, Texas. The portable airspace management capability developed by NASA will set the stage for requirements to safely enable BVLOS operations. The FAA has also established a workgroup with wildfire community which includes many federal collaborators such as the Department of Interior, United States Forest Service, Federal Emergency Management Agency, and NASA. This workgroup will adopt recommendations as per Section 910 of the FAA's reauthorization. NASA's PAMS and its use to support aerial monitoring, suppression, and logistics use cases by drones, particularly in DVE, will be a valuable NASA contribution to the workgroup's recommendations. NASA will also transfer PAMS and associated technology to industry, federal agencies (e.g., DOI), state agencies, and local and other stakeholders for their adoption.

D-4: PAMS Prototype Case Layout Diagram

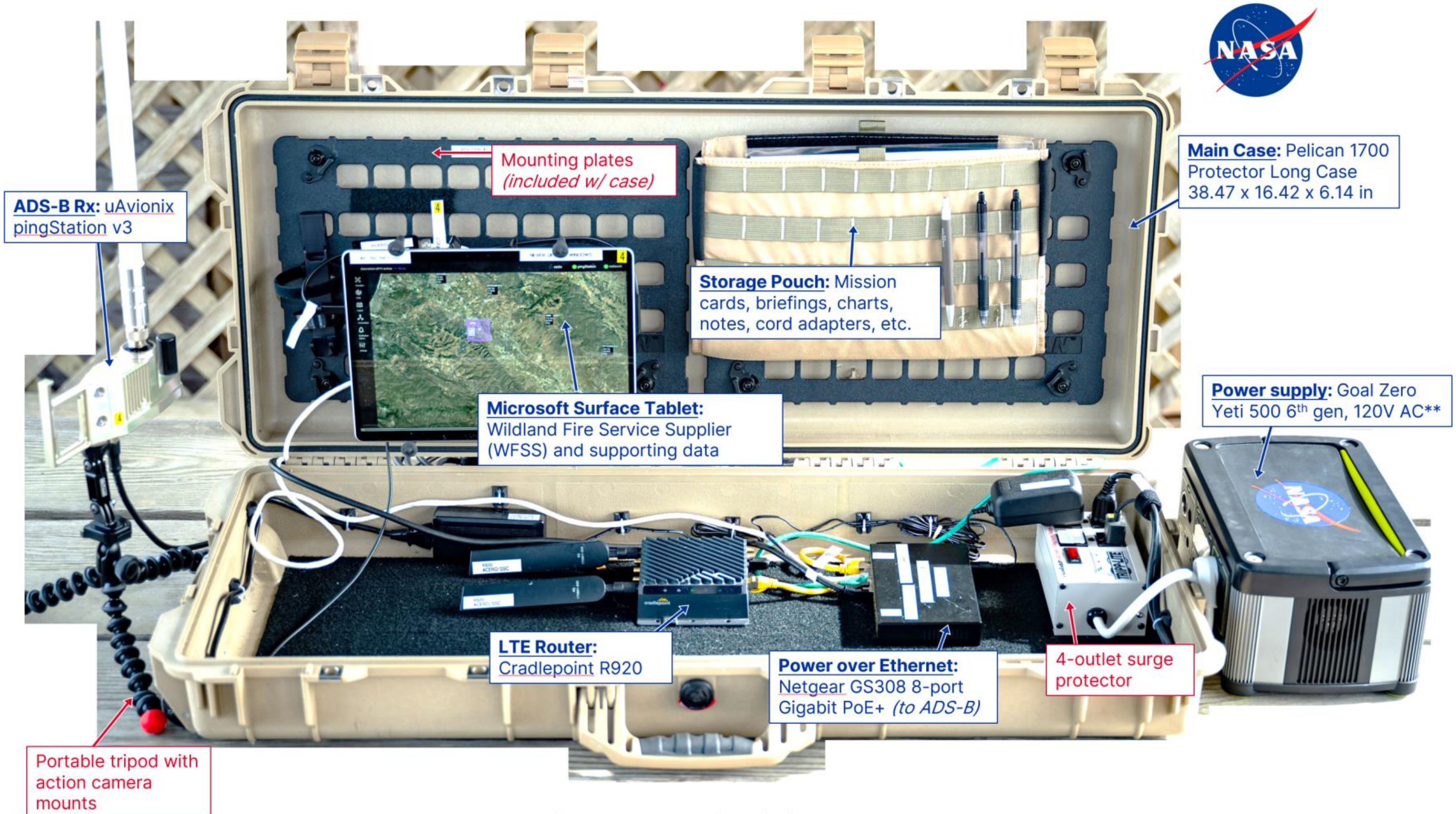

Figure 12 - First version of PAMS, one of the multi-nodes tested in TCL 1.

Acronyms

ACERO	Advanced Capabilities for Emergency Response Organization
ADS-B	Automatic Dependent Surveillance–Broadcast
AGL	Above Ground Level
AI/ML	Artificial Intelligence and Machine Learning
AOSP	Airspace Operations and Safety Program
AR	Augmented Reality
ARMD	Aeronautics Research Mission Directorate
ASTM	American Society for Testing and Materials
ATGS	Air Tactical Group Supervisor
ATM	Air Traffic Management
BIA	Bureau of Indian Affairs
BLM	Bureau of Land Management
BVLOS	Beyond Visual Line of Sight
C&C	Command and Control (also denoted as C2)
C&CAS	Coordination and Collision Avoidance System
CDC	Centers for Disease Control
CFIT	Controlled Flight Into Terrain
CFR	Code of Federal Regulations
ConOps	Concept of Operations
COP	Common Operating Picture
COTS	Commercial Off-The-Shelf
CRS	Congressional Research Service
DAA	Detect And Avoid
DHS	Department of Homeland Security
DOC	Department of Commerce
DOD	Department of Defense
DOI	Department of the Interior
DVE	Degraded Visual Environments
EA	Extended Attack
EO	Executive Order, or Electro-Optical
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FEMA	Federal Emergency Management Agency
FTA	Fire Traffic Area
FWS	Fish and Wildlife Services
GPS	Global Positioning System
IA	Initial Attack
IC	Incident Command(er)
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
IP	Initial Point
IR	Infrared (Radio)
ITC	Intertribal Timber Council
LRZ/LZ	Landing and Recovery Zone/Landing Zone
MSL	Mean Sea Level
MVP	Minimum Viable Product
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NASF	National Association of State Foresters
NIROPS	National Infrared Operations
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NPS	National Parks Service
NSF	National Science Foundation
NVD/G	Night Vision Device/Goggles
NWCG	National Wildfire Coordinating Group
NWS	National Weather Service
OMB	Office of Management and Budget
OPM	Office of Personnel Management
OWF	Office of Wildland Fire
PAMS	Portable Airspace Management System
PAO	Public Aircraft Operations
PMS	Publication Management System (NWCG)
RID	Remote Identification
SEAT	Single Engine Air Tanker
SME	Subject Matter Expert
sUAS	Small UAS (see UAV/S)
TCL	Technical Capability Level
TFR	Temporary Flight Restriction
TRL	Technology Readiness Level
UAM	Urban Air Mobility
UAV/S	Uncrewed Aerial Vehicle/System
US	United States
USDA	United States Department of Agriculture
USFS	United States Forest Service (within USDA)
USS	UAS Service Supplier
UTM	Uncrewed Traffic Management
V2V(2I)	Vehicle to Vehicle (to Infrastructure)
VFR	Visual Flight Rules
(V)LAT	(Very) Large Air Tanker
VMC	Visual Meteorological Conditions
WFSS	Wildland Fire Service Supplier
ZT	Zero Trust

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