NASA/TM–20220014721

# NASA System-Wide Safety Wildland Firefighting Operations Workshop Report

Sarah M. Lehman
*NASA Langley Research Center*

J. Tanner Slagel
*NASA Langley Research Center*

Sequoia Andrade
*KBR Wyle Services*

Hannah Walsh
*NASA Ames Research Center*

Alwyn Goodloe
*NASA Langley Research Center*

Summer L. Brandt
*NASA Ames Research Center*

Natasha Neogi
*NASA Langley Research Center*

September 2022

# NASA STI Program…in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA scientific and technical information (STI) program plays a key part in helping NASA maintain this important role.

The NASA STI program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI program provides access to the NTRS Registered and its public interface, the NASA Technical Reports Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services also include creating custom thesauri, building customized databases, and organizing and publishing research results.

For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at http://www.sti.nasa.gov

- E-mail your question via to help@sti.nasa.gov

- Phone the NASA STI Help Desk at (757) 864-9658

- Write to:
  NASA STI Information Desk
  Mail Stop 148
  NASA Langley Research Center
  Hampton, VA 23681-2199

NASA/TM—20220014721

# NASA System-Wide Safety Wildland Firefighting Operations Workshop Report

Sarah M. Lehman
*NASA Langley Research Center*

J. Tanner Slagel
*NASA Langley Research Center*

Sequoia Andrade
*KBR Wyle Services*

Hannah Walsh
*NASA Ames Research Center*

Alwyn Goodloe
*NASA Langley Research Center*

Summer L. Brandt
*NASA Ames Research Center*

Natasha Neogi
*NASA Langley Research Center*

National Aeronautics and
Space Administration

*Ames Research Center*
*Moffett Field, California*

September 2022

## Acknowledgements

The authors of this report would like to give a special thank you to Abigail Glenn-Chase and Anna Cavolowsky for performing multiple roles in the planning and execution the workshop. Another special thank you goes to Misty Davies and Kyle Ellis, the program manager and deputy program manager of the SWS project respectively, for supporting this work as well as for performing multiple roles in the workshop's execution, including serving as panel moderator and breakout session moderator.

This workshop would not have been possible without the speakers, panelists, panel moderators, breakout session moderators, and breakout session scribes, who made the workshop so engaging. A full listing of their names and affiliations is available in Appendix E. Similarly, the authors would like to thank the technical and logistics staff from NARI who ensured that the workshop—and workshop registration—ran smoothly. And, of course, enormous gratitude goes to all the people who registered and participated in the workshop; your service as subject matter experts made the workshop a success. We could not have enhanced the body of publicly available knowledge on wildland firefighting without you. Finally, the authors of the report would like to thank all those members of the SWS TC-5 ConOps Working Group who provided valuable input and feedback that helped to refine and mature the workshop report.





Available from:

NASA STI Program
STI Support Services
Mail Stop 148
NASA Langley Research Center
Hampton, VA 23681-2199

This report is also available in electronic form at http://www.sti.nasa.gov
or http://ntrs.nasa.gov/

# Table of Contents

# Acronyms and Definitions

ACERO.................................Advanced Capability for Emergency Operations
ADS-B ..................................automatic dependent surveillance-broadcast
AOSP ...................................Aerospace Operations and Safety Program
ARMD ..................................Aeronautics Research Mission Directorate
BVLOS .................................beyond visual line of sight
CAL FIRE.............................California Department of Forestry and Fire Protection
CAS.......................................Convergent Aeronautics Solutions
DAA.....................................detect-and-avoid
ESD......................................Earth Science Division
FAA .....................................Federal Aviation Administration
FIRMS .................................Fire Information and Resource Management System
JAXA ...................................Japan Aerospace Exploration Agency
LiDAR .................................Light Detection Radar
NARI....................................NASA Aeronautics Research Institute
NASA ..................................National Aeronautics and Space Administration
NextGen ...............................Next Generation Air Transport System
NOAA..................................National Oceanic and Atmospheric Administration
NRA.....................................NASA Research Announcements
NWCG .................................National Wildfire Coordinating Group
OAS .....................................Office of Aviation Services
SBIR ....................................Small Business Innovation Research
SMD.....................................Science Mission Directorate
STEReO ...............................Scalable Traffic Management for Emergency Response Operations
STMD ..................................Space Technology Mission Directorate
STTR....................................Small Business Technology Transfer program
sUAS....................................small unmanned aircraft systems
SWS .....................................System-Wide Safety
TFR ......................................temporary flight restriction
TFRSAC ...............................Tactical Fire Remote Sensing Advisory Committee
UAS .....................................unmanned aircraft systems
UTM ....................................UAS Traffic Management
VHF .....................................very high frequency

# NASA System-Wide Safety Wildland Firefighting Operations Workshop Report

Sarah M. Lehman[1], J. Tanner Slagel[1], Sequoia Andrade,[2] Hannah Walsh[3], Alwyn Goodloe[1], Summer L. Brandt[2], and Natasha Neogi[1],

## Executive Summary

NASA's System-Wide Safety Wildland Firefighting Operations Workshop engaged the broader wildland firefighting management ecosystem in a safety-oriented discussion via a virtual platform March 9–11, 2022. This enabled a better understanding of how NASA and community expertise can be leveraged in the safe development of current and future firefighting systems and operations. The goals of the workshop were to: (1) identify and prioritize the top safety-oriented risks, gaps in capabilities, and emerging technologies to enhance wildland firefighting for both near-term and far-term concepts, with a specific focus on aviation operations; and (2) engage the stakeholder community in defining emergent safety-oriented scope, roles, responsibilities, and procedures for agents undergoing increasingly complex wildland firefighting operations in information-rich, but uncertain environments.

Workshop participants were solicited from wildland firefighting stakeholders across government, industry, and academia. All levels of government were engaged as NASA sought attendees from federal, state, local, and tribal government agencies. Industry participants from traditional wildland firefighting domains such as data visualization and equipment manufacturers were invited and corporate attendees from novel application domains such as aerial robotics and autonomous systems were present as well.

Each day of the workshop had a different theme: (1) Operational Scope, Roles, and Responsibilities; (2) Standard and Emerging Operational Procedures; and (3) Prioritized Risks. Each day opened with a series of talks and/or panels to create a common knowledge baseline for all participants. This was followed by structured breakout sessions that captured the major concerns related to the day's theme in greater technical depth. Recordings of the presentations and panels, chat transcripts, and notes that were taken throughout the workshop were synthesized, reviewed, and analyzed to distill the key findings. The top three findings were: (1) enhancing situation awareness is a safety priority, especially in the use of aerial assets; (2) timely access to information along with data fusion and integrated displays will enhance safety-critical decision-making both inside and outside aviation contexts; and (3) tailorable standards and common operating pictures in the field will enhance inter-agency cooperation in the wildland firefighting lifecycle and enable the optimal use of limited resources such as aerial assets.

---

[1] NASA Langley Research Center, Hampton, Virginia.
[2] KBR Wyle Services, Moffett Field, California.
[3] NASA Ames Research Center, Moffett Field, California.

The workshop helped inform NASA of the relevant safety-related wildland firefighting concerns and aided the broader ecosystem in understanding the potential safety-oriented role NASA might play in this community. Increased engagement with crucial governmental stakeholders (e.g., U.S. Forest Service, CAL FIRE, etc.) along with industry partners in cutting-edge information-centric domains is a fundamental next step. Additionally, the workshop findings will help define the first of a series of operationally challenging demonstrations—held in concert with strategic ecosystem partners—known as the Safety Demonstrator Series for NASA's System-Wide Safety project. The first demonstration is set in the wildland firefighting application domain and will: (1) examine high risk operational scenarios to reduce their overall risk via services, functions, or capabilities that act as risk mitigators (or transfer that risk to automated systems better able to tolerate it); and (2) explore novel tools and technologies that will enhance safety margins by enabling non-traditional or neoteric operational paradigms.

# 1. Context and Motivation for System-Wide Safety Wildland Firefighting Operations Workshop

The System-Wide Safety (SWS) Wildland Firefighting Operations workshop, held March 9–11, 2022, brought together the wildland firefighting ecosystem with developers of increasingly autonomous systems to gain an appreciation of barriers and challenges to ensuring wildland firefighting operational safety. This workshop was held to address a gap in the wildland firefighting landscape in that it was specifically targeted to elicit the hazards, risks, and safety needs and requirements of wildland firefighting operations under today's taxing operational conditions. While previous workshops in the wildland firefighting community have sought to engage on the topic of improving the speed and efficacy by which wildland fires are detected, managed, contained, and extinguished thereby enhancing public safety and minimizing loss due to wildland fires, ***this workshop focused on improving the overall safety of the wildland firefighting operations themselves*** with a specific eye to improving the safety of aerial operations. This included addressing all stages of the wildland firefighting operation from pre-fire management of fuel sources, active management of wildland fires in both the initial and extend attack phases, post-fire management of smoldering areas, long-term land management, and prescribed burns.

The purpose of this report is to: (1) summarize the safety concerns of the wildland firefighting community that were discussed throughout the course of the workshop; (2) highlight and explain those safety concerns that are within the scope of the National Aeronautics and Space Administration's (NASA) SWS project; and (3) describe the role that NASA may be able to play with respect to operational safety in the context of the wildland firefighting ecosystem.

## 1.1. Background

While wildfire is a natural part of wildland ecosystems, uncontrolled wildfires threaten people, property, infrastructure, and resources. Wildland fire response is inherently hazardous and requires effective coordination between multiple operators and organizations across all levels of government for extended periods of time. This is compounded by limited communications and infrastructure in remote areas where wildfires are likely to occur and the fire event itself can damage what little infrastructure may be available (Martin, Arbab, & Mercer, 2021). Additionally, obtaining high-quality, up-to-date information about the fire location and rate of spread can be a barrier to effective decision-making (Martin et al., 2021).

In 2021, aviation accidents were the fourth leading cause of wildland firefighter fatalities behind COVID-19, medical, and vehicle accidents (Wildland Fire Lessons Learned Center, 2021). The use of small unmanned aircraft systems (sUAS) to reduce operational risk has been proposed. However, piloted fixed-wing aircraft are already in use for large wildland fires and integrating sUAS with existing aerial operations is challenging due to the complex flight paths required for firefighting missions in a shared airspace (Flight Safety Foundation, 2021).

## 1.2. NASA's Efforts in the Wildfire Management Lifecycle

NASA has a long history of contributions to wildfire management through the Science Mission Directorate (SMD), the Space Technology Mission Directorate (STMD), and more recently the Aeronautics Research Mission Directorate (ARMD) (Green, 2021). Of note is the NASA Disasters Mapping Portal which integrates multiple near real-time datasets into a single view with the goal of supporting disaster response and recovery, including tools for wildfire response. The portal includes active fire detection from the Fire Information and Resource Management System (FIRMS). Global Fire Weather Data enables the calculation of the likelihood of vegetation fire through windspeed and precipitation data. NASA's fleet of aircraft and airborne sensors, such as the ER-2 jointly operated by NASA Jet Propulsion Laboratory and NASA Ames Research Center's Airborne Sensor Facility, collects data about fire and smoke.

The Tactical Fire Remote Sensing Advisory Committee (TFRSAC), a collaborative partnership between NASA and the U.S. Forest Service, is a community of practice that identifies gaps in tactical fire information and prioritizes the development and transfer of technologies related to those gaps. In May 2021, NASA ARMD—in collaboration with SMD, the U.S. Forest Service, and the U.S. Air Force—provided a forum for representatives from wildfire organizations to share insights into community needs, challenges, and solutions to wildfire management (Kopardekar & Grindle, 2021). A stakeholder engagement workshop, held in February 2022, focused on innovations for detection and tracking, ecosystem management, and risk assessment tools and models (NASA, 2022).

## 1.3. Airspace Operations Safety Program Wildfire Efforts Activity Overview

The Airspace Operations Safety Program (AOSP), housed under ARMD, conceives of and develops Next Generation Air Transportation System (NextGen) technologies to further improve the safety of current and future aircraft through partnerships with the Federal Aviation Administration (FAA), industry, and academia. A large number of safety-oriented capabilities are under development in AOSP, including vehicle battery monitoring, prognostics of the performance of global positioning systems, and the assessment of risk of collision with obstacles or risks to people on the ground during UAS operations. AOSP intends to integrate these and other safety enhancing capabilities into a framework to assure the safety of future aviation operations.

AOSP is already active in the disaster management ecosystem. A partnership with the Japan Aerospace Exploration Agency (JAXA) successfully demonstrated the safe integration of an UAS Traffic Management (UTM) system with emergency response and disaster recovery activities in 2018 (Andreeva-Mori et al., 2020). The UTM project at NASA conducted research to enable sUAS access to low-altitude airspace beyond visual line of sight (BVLOS). NASA has also provided UTM capabilities directly to wildland firefighting through the Scalable Traffic Management for

Emergency Response Operations (STEReO) effort[4]. Through STEReO, NASA is engaged with the community to build a UTM-like ecosystem for wildland firefighting. This requires innovative communication approaches to enable new traffic management and autonomous vehicle capabilities and provides a data-rich common operating picture (Martin et al., 2021).

### 1.4. SWS Wildland Firefighting Operations Workshop Overview

NASA's SWS Wildland Firefighting Operations Workshop catalyzed a safety-oriented discussion in the broader wildfire management ecosystem. This helped NASA to better understand how community expertise can be leveraged in the safe development of current and future firefighting systems and operations. The workshop helped inform NASA of the relevant safety-related wildland firefighting concerns and aided in understanding the potential safety-oriented role NASA might play in this community.

The goals of the workshop were to: (1) identify and prioritize the top safety-oriented risks, gaps in capabilities, and emerging technologies to enhance wildland firefighting for both near-term and far-term concepts; and (2) engage the stakeholder community in defining emergent safety-oriented scope, roles, responsibilities, and procedures for agents undergoing increasingly complex wildland firefighting operations in information-rich, but uncertain environments.

The principal objectives of the workshop were to: (1) identify key safety challenges for wildland firefighting for both near- (e.g., 5-year time horizon) and mid-term (e.g., 10-year time horizon) operations; and (2) identify relevant stakeholders and potential partners for engagement and further focus group discussions. The workshop considered safety as it applies to the entire scope of the wildland fire management lifecycle, including: (1) pre-fire (fuel and ignition); (2) fire detection and tracking; (3) logistical deployment; (4) active fire mitigation and fire weather; and (5) post-fire survey. Additionally, prescribed burning as a means of risk mitigation was touched upon during the workshop. Since the SWS project is contained within NASA ARMD, emphasis was placed on identifying relevant aerospace considerations.

Participation in the workshop was solicited from stakeholders across government, industry, and academia. All levels of government were engaged as NASA sought attendees from federal, state, local, and tribal government agencies. Industry participants from traditional wildland firefighting domains such as data visualization and equipment manufacturers were engaged, and corporate attendees from novel application domains such as aerial robotics and autonomous systems attended as well. Key non-governmental organizations and academic institutions helped inform the state-of-the-art for future operations.

## 2. Approach in Generating Proceedings and Findings

The three-day workshop adhered to the same format each day with a general session followed by breakout room discussions. The general sessions included both individual speakers and speaker panels and were streamed over YouTube for workshop participants to view. Conferences io allowed participants to interact with comments and questions yielding interactive input. After the daily general session, registered participants joined one of up to six Microsoft Teams breakout rooms to

[4] STEReO was made possible through the programmatic commitment of NASA's Convergent Aeronautics Solutions (CAS) project under the Transformative Aeronautics Concept Program. The goal of CAS is to assess the feasibility of novel concepts and to support the transition of proven concepts into NASA projects to mature the enabling technology.

discuss the daily theme. Breakout discussions were not recorded but notes were taken. Along with the significant observations from the general sessions, the notes were distilled, categorized, and analyzed to extract relevant issues that were repeatedly raised across the workshop program and common insights that were derived from workshop interactions.

## 2.1. Summarizing Presentations of Invited Speakers and Speaker Panels

To summarize the presentations of invited speakers and speaker panels, the authors of this report reviewed all materials generated from the workshop, including video recordings, summaries drafted by session moderators, and notes taken by designated notetakers. Comprehensive sets of notes were generated for each session. Presentation summaries are provided in "Content of Workshop" (Section 3). Given that general sessions were broadcast over YouTube and recorded, speakers are identified by name and comments attributed to individuals where appropriate. Note that the summaries of the presentations represent the understanding of the material by the authors of this document; presenters were not necessarily involved in writing or reviewing these summaries.

## 2.2. Summarizing Breakout Discussions

To summarize breakout discussions, the authors of this document reviewed all materials generated from the workshop, including summaries drafted by moderators, notes taken by designated notetakers, and breakout room chat logs. Comprehensive sets of notes were generated for each breakout topic across all sessions. The summaries are also provided in the "Content of Workshop" (Section 3). Given that breakout sessions were not recorded, comments shared by participants were captured as general notes and individual names are not provided. Note that the discussion summaries represent the understanding of the material by the authors of this document; participants were not necessarily involved in writing or reviewing these summaries.

## 2.3. Synthesizing the Findings for the Entire Workshop

The authors of this document synthesized the findings contained in this report using multiple sources of background information (e.g., prior workshop reports, wildland firefighting operational handbooks, interviews with subject matter experts, etc.), along with the summaries created after the workshop. This includes information from prior workshop reports (Flight Safety Foundation, 2021; Kopardekar & Grindle, 2021; Martin et al., 2021; Mercer, 2021; NASA, 2022; USDA Forest Service, 2018), reports from the Flight Safety Foundation (Mooberry, Reeser, Yang, Millam, & Kirkman, in press), and external manuals and procedures for Wildland Firefighting (National Wildfire Coordinating Group, 2013; Department of the Interior and Department of Agriculture, 2022). The information was abstracted to a common level to be able to synthesize relevant findings.

Based on this refined information, salient points related to *safety-oriented barriers, challenges, and issues in wildland firefighting* that were sufficiently justified were considered findings by the authors. Assumptions, limitations, and flaws in the information were discussed before that information was used to support a proposed finding. Similarly, the existence of conflicting information was addressed when applicable and its influence on any finding was made explicitly clear. This core group of justified findings forms a major contribution of this workshop report and addresses the nature of NASA's potential role in the safety of wildland firefighting operations.

# 3. Content of Workshop

## 3.1. Operational Scope, Roles, and Responsibilities (Day 1)

The theme for Day 1 was operational scope, roles, and responsibilities. The general session opened with a welcome address followed by a review of the workshop goals and objectives and a presentation on the AOSP wildfire efforts. To round out the general session, an expert panel discussed organizational safety and safety roles regarding wildland firefighting. Workshop attendees registered for breakout sessions, joined their assigned virtual room, and continued a group discussion on operational scope, roles, and responsibilities.

### 3.1.1. Day 1 General Session

#### *3.1.1.1. Welcome*

The workshop opened with a welcome address by Mr. Steven Clarke, the Deputy Associate Administrator of NASA ARMD. In his welcome, Mr. Clarke discussed how this is one of many workshops that NASA has hosted with the wildfire community and remarked on the increasingly severe economic impacts of wildland fires. He mentioned that NASA is excited to engage with the community to see how best to leverage NASA's expertise to support firefighters at the tribal, local, state, and federal levels in prevention, mitigation, and recovery. NASA has the attention of the White House and President and has been charged to help mitigate the effects of wildfires.

Mr. Clarke emphasized that this workshop focuses on safety and that aerial firefighting is a dynamic and risky operation with multiple vehicle types entering and exiting firefighting areas. The SWS project, under the leadership of Dr. Misty Davies, Mr. Akbar Sultan, and Ms. Cheryl Quinn, is looking at ways to enable safer airspace for firefighting scenarios. SWS continues to mature and develop technologies that could be helpful to the wildfire community and could transfer technology to industry to be able to enable a safer airspace. Collaboration across industry, academia, and the government can collectively accomplish a great deal. Additionally, White House support and inter-agency agreements are expected to provide benefit to the wildfire fighting community. The ARMD integration of expertise across NASA for the wildland firefighting effort will be led by Dr. Parimal Kopardekar (also known as "PK") and Ms. Laurie Grindle.

#### *3.1.1.2. AOSP and SWS Wildfire Efforts*

Ms. Cheryl Quinn, the Deputy Director for AOSP, presented a high-level overview of NASA's AOSP. ARMD focuses on research that develops solutions to the major challenges and opportunities for aviation: a growing demand for mobility; the sustainability of energy and the environment; and technology advances in information, communications, and automation. AOSP is one of the five programs in ARMD. AOSP works with the FAA, industry, and academic partners to conceive and develop NextGen technologies to further improve the safety of current and future aircraft. AOSP performs research and technology demonstrations to enable safe, efficient, sustainable, and diverse operations.

Ms. Quinn stated that NASA has contributed technologies to improve the efficiency of operations in the national airspace, a prime example being UTM. UTM is a traffic management system for the management of sUAS traffic below 400 feet. NASA's UTM research on aviation operations has delivered air traffic management technologies to the FAA that are in the process of being deployed nationwide. AOSP is working on developing similar capabilities for a concept called Advanced Air Mobility, which is a farther term vision integrating highly automated electric vertical takeoff and landing vehicles for a variety of new missions such as Air Cargo Medical Transport and Urban Air

Taxis. AOSP works closely with the FAA and the aviation community to envision the future of aviation in the next 25 years and beyond.

Within SWS, NASA has demonstrated capabilities to improve safety throughout the commercial aviation domain. These tools include software assurance for the design of aviation and avionics systems that can greatly reduce cost in development; capabilities for analyzing large datasets of post-flight data to identify risks to commercial aviation operations; and the implementation of capabilities that monitor and assess safety risks within an operation in near real-time. Multiple services, functions, and capabilities are currently under research, development, and test, including vehicle health management; position, navigation, and timing prognostics and evaluation; and risk evaluation to third parties not connected to the operation (including persons and infrastructure). AOSP intends to integrate these capabilities into a framework to assure the safety of aviation operations.

Ms. Quinn also provided context regarding AOSP's involvement in wildland firefighting by citing that the agency has been engaged with the firefighting community through multiple mission directorates (e.g., SMD, STMD, etc.). Additionally, NASA has had a successful partnership with JAXA for an emergency response and disaster recovery demonstration. In this joint demonstration effort, JAXA developed the disaster relief aircraft management system, D-NET, for the operation, planning, and tracking of UAS and other assets during disaster relief operations.

NASA has also provided UTM capabilities directly to wildland firefighting through the STEReO project. Within this effort, NASA is engaged with the community to develop tools for common situational awareness and visualization of ground and flight assets such as tools for UAS pilot situational awareness and capabilities for establishing a more portable and resilient communication network.

Ms. Quinn highlighted that the most relevant parts of AOSP to this workshop are the safety management aspects specifically related to complex operations such as wildland firefighting. Ms. Quinn introduced the audience to three concepts that represent an approach to safety management: monitor, assess, and mitigate. Increasingly autonomous and complex operations will be enabled by monitoring and alerting for anomalies, assessing data from diverse sources to predict and alert for hazards, and mitigating actions that lessen the impact of hazards be it a human or system mitigation. She acknowledged that current-day wildland fire operations are manually oriented and AOSP looks toward future operations.

Ms. Quinn asserted that NASA's goal is to demonstrate a SWS framework and that areas of risk, types of data available, and what is needed to reduce that risk must be considered. She said that NASA wants to understand the wildland fire operation and asked the community to help NASA identify the top safety risks for use cases. Ms. Quinn ended by asking the community to engage and participate, to share experiences, and to help NASA think about how to leverage capabilities.

#### *3.1.1.3. Organizational Safety and Safety Roles Speaker Panel*

Dr. Evan Dill of NASA moderated the Day 1 speaker panel on organizational safety and safety roles. The panelists included:

- Ms. Sashi Sabaratnam, U.C. Cooperative Extension Wildfire Vegetation Mitigation Division
- Mr. Sean Triplett, U.S. Forest Service
- Mr. Brad Koeckeritz, U.S. Department of the Interior's Office of Aviation Services
- Ms. Dani Doyle, Colorado Division of Fire Prevention and Control
- Dr. Mike Pavolonis, National Oceanic and Atmospheric Administration (NOAA)
- Chief Geoff Marshall, California Department of Forestry and Fire Protection

Each panelist brought a unique background and perspective (see Appendix C for speaker biographies). Dr. Dill progressed the discussion from key near- and long-term challenges, to general questions from attendees, and concluded with major safety barriers. ***Challenges with obtaining and providing intelligence*** was mentioned by multiple panelists. A National Weather Service example was provided for clarification: When an incident meteorologist station is located at an incident, intelligence for impactful weather changes is clear and understandable. When the information is provided from remote weather forecasts offices, via spot forecasts, less information is available—increasing the difficulty of identifying impactful weather changes to resource deployment. The station location changes the ability to know and convey actionable safety information.

Additionally, ***voice and data networks (IT communications) face interoperability challenges*** as they are built to specific agency programs and areas. The wildfire arena uses a well-established, low-bandwidth communications platform (radio network) that works well in remote areas. However, at the urban-wildland interface, a more populated area with very high bandwidth and infrastructure, crossover with frequencies (i.e., sound transitioning from one audio source to another) and setups between the two programs leads to interoperability challenges.

Panelists also provided examples of ***communications challenges***. Not infrequently, the last good briefing a firefighter receives is at base camp around 0700 before they go to the fire line. If the situation changes radically, there is a robust radio network to share information. However, information that helps develop the common operating picture and map updates is lacking. Firefighters on the line do not have that larger picture. At the same time, having more information can overload the firefighters. There is a ***need to share information but to make it "bite-sized and digestible" to enable quick decision-making.***

Other highlighted challenges include a ***lack of coordination*** between federal, state, and local policymakers as well as ***limited relationships with the community and environmental groups***. The need exists to collaborate, to understand community concerns, and to share the problems from the practitioner's perspective. Similarly, the geopolitical environment poses a safety challenge. ***Every municipality operates differently*** with different politics, policies, programs, and interconnectivities. While local authorities do an astounding job of creating pre-season agreements and working fuel treatments and mitigation efforts together, "fires do not follow a geopolitical boundary: fires follow landscapes." The patchwork system through geopolitical boundaries impacts the way land is managed pre-, during, and post-fire. This combination leads to situations of fuel loading and fuel buildup in one area where another area could be very proactive. With land management and vegetation being significant contributors to large fires and with increasing fire intensity and severity, a call was made for long-term land stewardship planning from a global perspective that overlooked geopolitical boundaries.

A final stated safety challenge is the fact that ***experts are spread too thin***. It is time-consuming to develop knowledge, skills, and abilities to become experts in the field. As utility companies develop their own fire weather programs and other agencies develop fire programs, some experts are leaving the land management agencies—further limiting the pool of expertise. The question was raised how one might develop expertise without the need for 20 years of experience.

After the discussion of challenges, a series of questions were raised by the audience. Given that some panelists work at an agency level and some work at a local level, it was asked how much communication occurs and how well practices and policies translate across states. In response, it was pointed out that the California Department of Forestry and Fire Protection (CAL FIRE) has a good working relationship with land agency partners and shares common goals. A challenge CAL FIRE encounters is that they do not own the land on which they are trying to fight fire—as opposed to the Bureau of Land Management or U.S. Forest Service. As far as fighting fire in one state versus another, there are differences. For example, the comment was made that "we don't fight fire with leaf blowers out in California. But you go out to Tennessee, they can fight fire with leaf blowers." There are local differences with how to fight fire and talking with local agencies can reap benefits for any out-of-state resource coming in to help. It was added that agencies do try to learn from each other.

Panelists were then asked to discuss how they collaborate across agencies and to identify gaps. Marin County has tools to communicate with the community, tools for evacuation, tools for air quality, etc., however, ***in terms of gaps, different agencies have different purviews***. In California, there are state responsibilities and local municipality responsibilities which are funded at different levels based on community decisions. As mega fires become more prevalent, funding priorities shift but the concurrent cultural shift is not necessarily occurring.

***Communication is always a gap.*** The panel mentioned the National Wildfire Coordinating Group (NWCG) as the mechanism for coordinating among federal, state, local, and tribal partners. As such, under the NWCG all participants are working from a common set of protocols and procedures. NWCG is the umbrella that provides the training and policies to allow 600+ agencies to work together as needed during an incident.

***Training is also a gap.*** Firefighters require time to develop experience. The workforce is aging and experienced leadership in firefighting and related fields is being lost. With increasing fire intensity, increasing urban-interface challenges, and decreasing experience with new firefighters, significant safety-related challenges lie ahead. Stretched resources and more fire incidents increase the importance of operational and sustainable fire behavior prediction.

Furthermore, data driven, experimental products developed for one region may not translate to another. As on attendee stated: "Micro-weather models developed in Denver probably won't work in California."

As the final question, panelists were asked to identify the biggest barrier to safety and what changes or additions could help. Ms. Doyle advocated for increasing interoperability between agencies and organizations from small scale (e.g., harmonizing of radio bands, etc.) to large scale (e.g., adopting of new technology, etc.) as a top concern. She emphasized the necessity of continuous collaboration and relationship-building along with the fact that technology can be a hinderance but can also be used to great advantage. Mr. Koeckeritz brought up the issue of reducing wildland firefighter fatalities. He asserted that there should be new safety features for the new generation of vehicles being deployed. He asked the question of whether it might be possible to move away from operations with "large, crewed planes running six hours a day dumping thousands of gallons [of retardant]" towards uncrewed systems. He said that the most useful air operation to make autonomous would be "low, slow, single engine ops." Mr. Triplett stated that the job is currently inherently risky and that there is a lack of experience in the frontline due to stretched resources. Coupled with the political pressure to perform, these factors amplify risk. He mentioned that there are also mental health issues and physical fatigue concerns because there is no downtime for wildland firefighters due to the extended wildland firefighting cycle. Mr. Koeckeritz supported this assertion by mentioning the occurrence of entrapment events. He mentioned how leaders making these decisions know the risk but decide to move forward anyways for a variety of potentially non-technical reasons.

Ms. Sabaratnam was concerned about what can be done to reduce flame length and how data can be used to tell a story for the public. She emphasized that efforts towards items like fuel reduction may be less appealing to wildland firefighters but that they are critical. Chief Marshall stated that connectivity issues are a part of human factors issues. He emphasized that everyone needs to be working from the same map. He mentioned that there also needs to be better accountability and that a common operational view could influence leaders' decisions. This could then lead to a reduction in human factor errors (though elimination). Dr. Pavolonis agreed that human factors issues were key to safety and that actionable capabilities for decision-making on the ground must be available and scalable. Specifically, he defined "human factors" as a person's capability to make informed decisions. He mentioned that a test bed as well as effective operational practices were needed. Communication, resources, teamwork, knowledge, training, and norms are human-factors related challenges influencing safety-critical behavior.

### 3.1.2. Day 1 Breakout Sessions

The Day 1 breakout sessions focused on identifying the primary safety-critical decision makers for wildland firefighting, investigating decision maker coordination, common safety-critical decisions, and challenges in this decision-making process. Approximately 85 participants—from more than 65 different agencies spanning government, industry, and academia—separated into six breakout rooms. (See Appendix D for a list of participating groups.) Following is a distillation of the information received during these breakout sessions.

#### *3.1.2.1. Relevant Decision Makers in Wildland Firefighting*

During the pre-fire stage, the agency in charge of potentially affected land is the primary entity responsible for surveying, fuel breaks, and other vegetation management techniques for the prevention of wildfires. In the case of a fuel break (i.e., the alteration of blocks of vegetation to slow or control future potential wildfires), the necessary permissions must be given by the surrounding community and local government.

Fires are initially reported to the Emergency Communication Center (typically through a 911 call or observation by fire service personnel). The Emergency Communication Center produces a run card of task forces and resources assigned to the fire and, if the fire is of a significant size, an Incident Commander may be assigned at that time. The Incident Commander oversees directing resources and communicating with fire management officers, road organizations, power companies, and local law enforcement to orchestrate the task of putting the fire out safely. For small fires, the initial response is primarily at the local and state level. Federal agencies such as the U.S. Fire Administration, Federal Emergency Management Agency, the U.S. Forest Service, and the U.S. Department of the Interior get involved in the wildland firefighting if the fire becomes large or spreads onto federal land. To aid in coordination and communication between all these agencies, the National Multi-Agency Coordinating Group offers incident and logistic information, predictive services, and training, among other services. To assist in wildfire coordination, the NWCG provides established inter-agency wildland fire operation standards and wildland fire position standards, works to establish information technology requirements for wildland fire, and supports the goals to restore and maintain resilient landscapes and fire-adapted communities.

#### *3.1.2.2. Common Safety-Critical Decisions*

Wildland firefighting involves safety-critical decisions at every stage of a wildfire. During the pre-fire stage, the placement locations of fuel breaks are of paramount importance: An effective fuel break can be the difference between a wildfire that can be extinguished at a local level versus a fire that spreads and becomes a national issue. Additionally, thorough surveying of high-risk land in the pre-fire stage can make essential information about vegetation and fuel sources available to agencies during a wildfire and can contribute to situational awareness.

During the early stage of a fire, quick decisions on resource distribution and what part of the fire to fight first are essential to effective mitigation. As the fire progresses, firefighting organizations must decide to let a fire burn or to make a stand to prevent spreading (e.g., when the fire approaches residential areas). Additionally, evacuation orders to protect local populations around a spreading wildfire must also be issued. On the frontline, fire fighters must decide the best way to carry out their assigned mission while keeping a safe distance and having a clear path to safety around the wildfire area.

#### *3.1.2.3. Challenges in Safety-Critical Decision-Making*

***Maintaining appropriate situational awareness throughout every stratum of the wildland firefighting response team is essential*** to making the safest and most effective decisions in an environment that is highly complex and quickly changing. ***To achieve a common operating picture and ensure the best decisions are being made, up-to-date and useful data must be available to everyone.***

Currently, firefighters in remote wildland areas face ***bandwidth issues***. To receive up-to-date data, weather, and map information, it is common for firefighters to receive data on their smartphones or tablets when they return to their camp once or twice a day. This results in firefighters using what is called "stale" data in the field. When firefighters lack updated weather and prediction information, wildfires can spread in unexpected ways, resulting in the loss of a path to safety that could lead to serious injury or loss of human life.

One participant pointed out a communication system shortcoming that resulted from the main office command post having information unavailable to the frontline people. For example, hot shot crews consist of specially trained fire fighters who respond to high priority fires. Hot shot crews require up-to-date fire perimeter information when deciding whether to attack or backfire (i.e., intentionally set a fire along a fire line's inner edge to consume the fuel in the path of a wildfire). Data need to be "pushed to the hood of the truck" from the main office but cell service or very high frequency (VHF) are limited to the frontline people.

In addition to potentially low bandwidth in the field, ***data sources are decentralized*** across many different agencies. There is no one centralized authority with the most up-to-date data, which results in data being sent manually to personnel. While UAS were mentioned as a potential solution to provide essential data for safe and effective wildfire operations, additional challenges of ***ensuring the safety of aircraft operations*** (e.g., vehicles remain in their operational volumes, remain well-clear of other vehicles and firefighters, can withstand the turbulent environment, etc.) were also discussed.

On the other end of the data pipeline, there is a need for more effective data fusion and analysis that renders results that are easy to understand and act upon. Frontline workers face heavy workloads and stressful environments that do not leave much time or mental capacity for technical analysis and data interpretation. Data need to be processed and displayed in a way that supports decision-making. This could be a visual interface that considers the fire traffic area from a bird's eye view showing information such as operating and wildfire volumes, weather, topography, and fuel mapping information.

## 3.2. Standard and Emerging Operational Procedures (Day 2)

The Day 2 theme was standard and emerging operational procedures. The general session included a presentation and panel discussion: The presentation reviewed the STEReO project and the panel discussion with subject matter experts addressed the day's theme. Breakout sessions focused on identifying standard operating procedures of a "routine" day of wildland firefighting.

### 3.2.1. Day 2 General Session

#### *3.2.1.1. Scalable Traffic Management for Emergency Response Operations Project*

The second day of the workshop began with a presentation by Mr. Robert McSwain of NASA on the STEReO project, describing the work performed on this effort over the first two years. The STEReO project addresses the problem of how to support natural disaster and emergency response operations using the UTM, which was originally developed at NASA Ames Research Center from 2015 to 2020 (FAA, 2022; Robinson, Johnson, Kopardekar, Preot, & Rios, 2015). In particular, the project focuses on how to maintain operations in the face of real-world complications such as adverse weather conditions, limited communications and utility infrastructure, the need to manually coordinate affected airspace, and the time-sensitive nature of data and decision-making.

STEReO began with a workshop in February of 2020 when the team met with stakeholders and emergency response subject matter experts to learn more about their needs. Using the insights gained from the workshop, the STEReO team organized the efforts along five swim-lanes. Each swim-lane was dedicated to a different focus area with tailored objectives based on workshop take-aways: ***Autonomy*** (focused on autonomous aircraft management and capability); ***Communications*** (focused on data sharing and infrastructure); ***Human Factors*** (focused on end-user-centric design); ***UTM Services*** (focused on UAS Service Provider capabilities); and ***Domain Expertise*** (focused on leveraging operational insights from subject matter experts and maintaining continuity with established workflow processes).

Leveraging these five areas, the preliminary version of the STEReO system architecture focused on improving and supporting data exchanges between emergency response actors; this includes exchanges between air vehicles, ground vehicles, personnel, and existing infrastructure. In doing so, the STEReO system helps maintain common situational awareness between responders as well as streamline and improve aircraft operation scalability.

#### *3.2.1.2. Standard and Emerging Operational Procedures Speaker Panel*

After the keynote presentation, Day 2 of the workshop continued with a panel discussion on standard and emerging operational procedures in wildland firefighting. The panel was moderated by Dr. Jon Holbrook of NASA and comprised of six speakers (see Appendix C for speaker biographies):

- Mr. Mark Bathrick, Bathrick Aviation Consulting
- Chief Richard Fields, Los Angeles City Fire Department
- Mr. Dirk Giles, U.S. Forest Service
- Mr. Coitt Kessler, DroneSense
- Chief Chris Tubbs, Southern Marin Fire Department
- Chief Charles Werner, DRONERESPONDERS

Dr. Holbrook opened the panel with the question of key near- and long-term challenges. The first near-term challenge cited was ***human factors*** concerns in wildland firefighting since 70% to 90% of all mishaps that occur have human factors as a contributing or primary cause. Thus, any new technologies, emerging procedures, and training should be designed with appropriate considerations of human performance and integrated such that they do not incur additional human factors-related costs which can cause additional safety challenges. Another short-term challenge centered around ***integrating UAS technology*** to allow for fire detection and response in incipient stages. This was seen as enabling fire management to, at minimum, hold the fire in check until further resources are brought to bear. A long-term challenge to address is the ***inability to access a wide variety of UAS platforms*** as federal entities are constrained to using only domestically manufactured products. ***Training and standardization*** are also safety challenges; as tools become more advanced and payloads (and vehicles) become larger, it becomes even more important to ensure that these assets are being operated in a safe manner.

As fires progressively get larger and the fire season becomes a year-round affair, this impacts several major concerns for wildland firefighting efforts. ***Staffing and task saturation*** for the people involved is seen as a significant challenge. Without any opportunities for respite, burnout and attrition in the workforce becomes a dangerous situation that gives rise to many human factors-related problems. The ability to staff correctly, fund adequately, and train sufficiently is crucial to resolving these human factors issues. Technology aids and assistance may ameliorate this problem but only in a supplemental role to ensuring that all human agents have adequate experience and capability to execute their tasks. Another long-term challenge mentioned was the fielding of a reliable communications system. There is a need for persistent, dedicated communications infrastructure for the duration of the wildland firefighting response mission because 95% of U.S. Forest Service or interagency partners incidents are in a disconnected environment. The goal of being able to share data in real time between agents with near zero latency would be extremely beneficial to the overall safety of the operation. This need for ***persistent communications to connect the fielded technology platforms*** proved to be a common theme for several of the panelists as a fundamental challenge and several panelists mentioned the fact that the Department of Defense has persistent communications solutions that have potential to address this problem in the wildland firefighting context but have not been tested in this domain. A ***need for executive direction and leadership*** was also introduced as a central challenge since it is necessary to have a coordinated approach outlining how multiple agencies work together and harmonizing standards and training across agencies is a vital topic.

Reducing the risks from the threat of wildland fire by ***increasing community preparedness*** was mentioned as a significant challenge. Similarly, the impact to personnel due to the increasing scale and scope of wildland fires was highlighted and broadened to include the effect on persons who are not directly in the field (e.g., station managers, etc.). Furthermore, the ***prioritization and standardization of rules, regulations, and procedures*** as applied to not just active wildland firefighting but ***to the entire wildland fire management lifecycle*** was reinforced. ***Airspace coordination*** was cited as a fundamental problem in the deployment of aerial assets (including UAS) to support wildland firefighting operations and to improve overall safety of the operation. The notion that solutions must be scalable and apply beyond a single geographical area (or state) was a central point that was made, considering the size, scale, and prevalence of wildfires across the U.S. The challenge of flying aircraft in hazardous environments or hazardous weather lends itself to deploying UAS in order to redistribute risk to agents who may be better able to withstand it. Finally, the ability to work with regulatory agencies, such as the FAA, in order to be able to ***quickly, repeatably, and safely field UAS to support wildland firefighting operations*** is seen as a central challenge. Operations like persistent, BVLOS UAS flight above the temporary flight restriction (TFR) would aid in improving situation awareness throughout the wildland firefighting operation for operations like wildfire detection, wildfire suppression, and fuel and ignition source monitoring which touches on the wildland fire management lifecycle.

Dr. Holbrook asked the panelists to describe a routine day in wildland firefighting. Two themes emerged while panelists discussed necessary improvements to standard operational procedures: ***1) enabling air operations for a mix of manned and unmanned vehicles; and 2) deploying modern sensing and data communication to improve situational awareness.*** Panelists agreed that mixed-manned and unmanned aircraft operations have the potential to greatly improve the effectiveness and efficiency of wildland firefighting. Panelists noted ***UAS as particularly useful in providing long-term, mid-range sensing capabilities over large geographic areas***—such UAS utilization would support early fire detection in scenarios where satellites are limited by cloud coverage or limited observation times and promote more effective use of suppression resources such as water drops. Other uses for UAS include performing pre- and post-fire surveys, dropping incendiary devices for controlled burns, and scanning for hotspots. However, several challenges stand in the way of formally integrating UAS into standard operating procedures. Chief Fields noted that even though the City of Los Angeles already deploys several sUAS for wildland firefighting, the ***purchase and operating costs for such systems are heavy burdens for state and local budgets***. There are also regulatory concerns surrounding the use of UAS. Operating both manned and unmanned aircraft in the national airspace above active fires requires both ***waivers from the FAA and fine-grained traffic management*** to ensure, as Mr. Kessler observed, that "plastic isn't bumping into metal in the airspace." Finally, the design of any UAS deployed in such an environment would need to intensively consider human factors to ensure usefulness of the system without endangering firefighters and pilots in life-threatening situations.

The second theme of discussion (sensing and communications) centered around the efforts involved in maintaining and improving situational awareness, which has a direct impact on firefighter safety. While UAS can provide more fine-grained sensing capabilities than satellites, the problem remains of delivering that collected data to the appropriate stakeholders. Because wildland firefighters usually operate in remote and hostile environments lacking cellular or other modern data communications, standard operational procedures rely on radios and hand-carried messages for communication between firefighters and their commanders. Almost all the panelists agreed with the need to introduce modern data networking capabilities that would enable up-to-date data to easily be communicated to the people who need it when they need it. This includes presenting firefighters in the field with data such as weather updates, fire location, real-time sensor readings, or locations of potential fuel sources and field commanders with the locations of their firefighters or the latest predictions from fire behavior models. Panelists noted, however, that ***ensuring the scalability and reliability of such a communications network would be a major challenge***, one which may be alleviated with distributed solutions such as ad-hoc networks and edge computing to connect data recipients in the air, in the field, and at the command station. Chief Werner also stressed the need to leverage commercial communications platforms such as WhatsApp in scenarios where infrastructure is available and responders need to establish lines of communication quickly. Another major challenge identified by panelists is ***ensuring that data, once received, is properly filtered and presented in such a way as to prioritize that which is necessary for immediate decision-making*** and not to overwhelm or distract the firefighting team.

The panel closed with a discussion on anticipated future innovations in wildland firefighting technology as well as barriers to adopting that technology. Several panelists expressed a desire for high availability and portable connectivity, though contemporary smart devices require a network connection that is simply not present out in the wildlands. Chief Tubbs expressed excitement for "having the right information at the right time in the right way" with all the visualization and interaction capabilities afforded by emerging fields such as augmented and virtual reality, artificial intelligence, and machine learning. The panelists also expressed a desire for more open and standardized access to UAS, including automation to support functionality such as detect-and-avoid

(DAA), BVLOS, and 24-hour continuous flight capabilities. However, the panelists identified several barriers impeding the realization of these innovations. The most immediate barrier, identified by Mr. Bathrick, is to ***overcome years of deeply ingrained practices to incorporate new technology into firefighting practices***. Mr. Bathrick suggested a "build-up approach" of technical tests and demonstrations to incrementally build familiarity, acceptance, and excitement among firefighters for new technologies. However, the greatest barrier, as identified by Mr. Kessler and echoed by Chiefs Werner and Fields, was indicated to be a ***lack of "executive direction and leader intent."*** Local and national leadership have the power both to mandate when new technology is necessary and to fund its development. If this were to happen, resistance to adoption experienced by the "boots on the ground" would greatly diminish. However, any such unified effort and commitment has so far been absent among wildland firefighting leadership.

### 3.2.2. Day 2 Breakout Sessions

The Day 2 breakout sessions were focused on identifying standard operating procedures of a "routine" day of wildland firefighting, challenges in following standard operating procedures, and how those challenges are typically addressed. There were six breakout rooms with approximately 60 participants from more than 45 different agencies spanning government, industry, and academia. (See Appendix for a list of participating groups.) Following is a distillation of the information received during these breakout sessions.

#### *3.2.2.1. Safety Impacts of Routine Operations*

Many of the safety-related challenges to decision-making discussed on Day 1 arose again when participants discussed safety impacts in routine operations. In general, participants identified ***situational awareness*** as having the largest impact on safety during a routine day. This encompasses several specific foci, chief among them ***effective data communication.*** As mentioned on Day 1, communication is often limited in wildland areas and firefighters in the field are often limited to "stale" data previously collected at base camp to support decisions during operations. In a wildfire area, weather conditions and fire data can change quickly; if the fire spread changes course and firefighters have inaccurate data, the situation can become dangerous. Radio communication is possible when actual fire spread does not match the predicted fire spread and the path to safety is unknown but channels saturate quickly and essential information can become difficult to communicate in a timely manner.

In addition to the need for a better communication infrastructure, there are the juxtaposed issues of having large amounts of data from many different sources that is hard for personnel to analyze effectively and understand quickly and a lack of data in some essential areas such as local weather information and real-time fire spread information. These two issues hinder the ability of personnel to make timely, safe decisions. The former issue, colloquially known as ***"paralysis by analysis,"*** points to the need for tools that collect, process, organize, analyze, and visualize data in a clear and quick way. The latter issue points to the ***need for new/additional technology*** in the field to collect and send real-time data on fire behavior, weather, and fire-fighting operations. For example, UAS can provide live fire mapping, fire lookout cameras that show field of view, and fuel source and vegetation mapping in real-time. Additionally, aircraft that have sensors can measure current weather information and help in the real-time prediction of fire spread. Participants pointed out that as more unmanned and manned aircraft enter the fire-traffic area, situational awareness between these aircraft (particularly: remaining well-clear of each other, firefighting crews, and remaining in a safe area) have large safety implications.

***Overworked and under-resourced*** firefighters is another prominent safety concern for the routine day. There are roughly 25,000 firefighters in the nation at any given time but anecdotes from operational wildland firefighters during the breakout sessions asserted that resource requests for active fires can quickly top 50,000. Participants gave examples of limited resource scenarios and noted that firefighters sometimes do not submit a resource request because they believe it will be rejected. Undoubtedly firefighting organizations need more wildfire fighting personnel on the ground and more available resources. Firefighters need new equipment, technology, and communication capabilities but the resources must focus on ease of implementation, understanding, and use by firefighting personnel who are likely fatigued and overworked. Firefighting groups can hesitate to adopt new technology because of perceived costs to incorporate new procedures and applications and cost to "unlearn" the previous, well-established system.

#### *3.2.2.2. Challenges of Routine Operations and Their Workarounds*

Workshop participants identified ***data and communication issues*** as the greatest challenge impeding successful, routine, daily operations. These include multi-faceted concerns such as: data streams that are numerous, varied in nature and format, and difficult to sift through to find meaningful insights; the "hard copy" data that firefighters carry that quickly becomes outdated but infrastructure gaps prevent transmitting new data; and over-crowded radio channels with no reliable alternate method to disseminate forecast updates and hazard warnings, all of which exacerbates risk. To address these challenges, participants proposed solutions such as further organizing data storage and visualizations, merging fire behavior models to generate more "well-rounded views," and improving data connectivity for personal devices such as smartphones.

Workshop participants also identified several challenges that obstruct new technology adoption into their wildfire fighting practices. The foremost concern mentioned is ***lack of funds and resources*** available to firefighting organizations across the board. New technology is expensive and both human and technological resources are already in short supply for firefighting engagements. Participants indicated a "struggle to fund moderate forest health projects that would make larger suppression efforts more efficient." Further, positively identifying fire, and lack of fire, in remote areas is challenging; precious resources are committed to verify the absence of fire. All this strains an already limited resource supply, leaving even less in reserve for adopting new technology.

Availability of ***sufficiently ruggedized systems*** was another challenge when adopting new technology; any new firefighting technology must be able to handle inconsistent communications and incomplete power infrastructure and be lightweight enough to carry (or mount to an aircraft) and operate using battery power. Restricted funding resource availability requires systems to be backwards compatible and support a "right to repair;" this would restrict firefighting agencies from purchasing new systems every couple of years. Firefighting crews have relied on paper maps and radios precisely because it is so difficult to find new technology that meets all these needs. Any new technology also faces the challenge of overcoming tradition; not only must the potential system be worth the physical and financial cost but it must also be worth the mental cost involved in training firefighters to unlearn old habits and adopt the new technology.

Participants added the interpersonal ***conflict between firefighting groups*** and their associated jurisdictions as a major challenge in observing routine operations. Disparate firefighting groups, government entities, and local stakeholders all have unique sets of wildland firefighting policies, priorities, and operational procedures that rarely align with one another. When technology changes hands (such as when the Forest Service seeks to adopt systems developed by the Department of Defense) or when an active fire crosses jurisdictional boundaries (such as out of the wildland and onto a vineyard), ***communication, coordination, and transfer of responsibility present a significant challenge.*** Participants indicated that improving general communications infrastructure and data sharing capabilities, including standardizing operational procedures between groups, are open research problems.

Finally, workshop participants identified ***firefighting hero culture*** as a source of conflict when it comes to following standard operating procedures and minimizing safety risk. They observed that firefighting is generally seasonal work; if firefighters are not working, they are not getting paid. This encourages some to take on more frequent and longer assignments than is advisable. Additionally, decentralized leadership, limited resources, and funding pressures for firefighting communities means that community members are not given, or do not feel comfortable in taking, the opportunity to say "no" to a given fire suppression assignment. This undue pressure, combined with a general atmosphere of heroism and pride, contributes to firefighters' inadequate or insufficient adherence to safety protocols and safety equipment uses.

## 3.3. Prioritized Risks (Day 3)

The theme for Day 3 was prioritized risks. The general session consisted of two panel discussions: the first with NASA leaders who discussed existing wildfire-related efforts across NASA; and the second with subject matter experts who discussed "The Art of the Possible." Breakout sessions focused on identifying and prioritizing safety related risks and threats experienced during wildland firefighting and exploring related mitigations.

### 3.3.1. Day 3 General Session

#### *3.3.1.1. A Conversation with NASA Leadership on the Wildland Firefighting Ecosystem*

Dr. Jessica Nowinski of NASA Ames Research Center moderated the first panel, "A Conversation with NASA Leadership on the Wildland Firefighting Ecosystem." The panelists included four leaders from NASA:

- Dr. Parimal Kopardekar, Director of NASA Aeronautics Research Institute (NARI)
- Dr. Misty Davies, Project Manager of the System-Wide Safety, Aeronautics Research Mission Directorate
- Dr. Barry Lefer, Tropospheric Composition Program Manager, Science Mission Directorate
- Mr. Jason Kessler, Manager of the Small Business Innovation Research and Small Business Technology Transfer Programs, Space Technologies Mission Directorate[5]

Wildland firefighting includes high-risk aerial operations, especially when flying both manned and unmanned vehicles in variable environments with limited visibility. Numerous NASA research and technology investments address the operational challenges of wildfire response operations challenges. For example, UTM systems are relevant to the challenge of safely integrating unmanned and manned aerial operations. Additionally, implementing an in-time safety management system for monitoring, assessing, and mitigating risks offers improved safety in emergency response operations. NASA has also developed advanced on-board sensors and satellite remote sensing technology which can provide relevant data to decision makers and improve emergency response operator situational awareness. While getting new technology into operations can be a challenge, NASA's Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs specialize in funding technology development and transferring tools to real operations.

[5] https://sbir.nasa.gov

NASA has been addressing safety challenges related to wildfire response through internal and external collaboration and the leaders emphasized the importance of continuing collaboration moving forward. One collaboration opportunity is to use NASA-developed UTM to coordinate medium to large UAS to enable increased wildfire response operations. Ongoing NASA projects developing technology, including detection sensors, have potential applications in pre-fire, active fire, and post-fire management but multi-organizational collaboration is required to transfer these technologies. For example, specialized airborne sensors previously developed by the Earth Sciences Division (ESD) can map fuel loading and gather data through smoke to determine the fire state (smoldering, flaming, etc.). In collaboration with external partners (e.g., U.S. Forest Service), this technology could be used to map fuel areas for pre-fire and active fire monitoring. NASA and the SWS project have world-class expertise on safety and risk management in aviation; continued collaboration with wildfire experts will further understanding of risk and hazards unique to emergency response operations. Through the SBIR program, NASA is actively collaborating with small businesses to fund wildfire relevant developments, such as decision support tools, and will continue to fund new collaborations in the future. Across the agency, NASA has collaborated internally between directorates and externally with small businesses to develop state-of-the-art technology, including high-tech sensors and autonomous systems, which have the potential to address wildland fire operation challenges.

NASA has a successful track record in developing tools and technologies relevant to the wildland fire ecosystem and is a world-class leader in developing safe, scalable, autonomous systems with advanced sensing capabilities. For example, UTM began around 2012 and has developed into an accessible, self-contained (i.e., ‘UTM in a box’) system compatible with automatic dependent surveillance broadcast (ADS-B) systems on piloted aircraft. Together, this system can monitor sUAS used by fire departments in a complex air traffic environment. This system has been explored through the STEReO project via a flight test demonstration that employed sUAS in a simulated response to a potential wildland fire scenario (and not a live fire exercise). In 2019, the ESD partnered with NOAA and the U.S. Environmental Protection Agency to study the health effects of smoke using aircraft equipped with advanced sensors, including Light Detection and Ranging (LiDAR). These sensors successfully monitored fire intensity, smoke dissipation, and smoke plume height to ultimately map where smoke travels during wildfires. SWS currently has 22 safety services active in test flights and operations that identify risk from factors such as radio frequency interference, population density, and flight into obstacles. Ongoing safety research works to automatically identify risks through advanced natural language processing capabilities applied to traditional aviation safety reporting systems. External companies funded through NASA’s SBIR program have also developed advanced technologies. For example, there is a company that is actively developing a highly accurate fire management decision support tool to predict and monitor wildfires using physics, data, and both space and ground sensors.

NASA aims to transfer technology to stakeholders for operation and this includes wildland fire experts. Specific technologies identified for transfer include advanced fuel monitoring sensors and UTM for wildfire response. On numerous occasions NASA has successfully transferred matured capabilities to real-world operations. However, for these technology transfers to succeed a multi-sector, multi-organizational, collaborative approach is vital. A robust understanding of stakeholder needs can foster better understanding and successful handoff points. Multi-sector and multi-organizational collaboration, including through workshops, enables a clarity of stakeholder needs and alignment to ensure tools and technologies under development are applicable and useful to future customers. During this conversation the NASA leaders defined NASA as an agency with a strong technology transfer program intended to get tools and technologies to external agencies for operations.

### *3.3.1.2. The Art of the Possible Speaker Panel*

Dr. Natasha Neogi of NASA moderated the second panel on the art of the possible and examined safety risks and opportunities in wildfire communities with subject matter experts (see Appendix C for speaker biographies). This panel included:

- Mr. Don Berschoff, TruWeather Solutions
- Mr. Everett Hinkley, U.S. Forest Service
- Dr. Ivan Pupulidy, University of Alabama at Birmingham
- Mr. Matt Quinn, Great Lakes Drone Company
- Mr. Anthony Schultz, Environmental Systems Research Institute

Similar to the previous days, Dr. Neogi opened the discussion by asking the panelists to identify key near- and long-term challenges. Panelists identified short-term challenges including ***bureaucratic inertia and processes, data transfer and communications in the disconnected operational environment*** (i.e., limited bandwidth), and the ***need for more accurate, detailed data***. Long-term challenges preventing widespread adoption of novel technologies include a ***lack of scalability of solutions, a lack of advanced predictive data analysis, and uncertainty in predictions and novel systems***. While there are novel technologies that work well in certain environments, region specific differences and bandwidth limitations prevent scaling to all wildfire operations. Advanced predictive capabilities, especially in the thirty-minute to six-hour range, are highly desirable; however, quantifying and understanding prediction uncertainty is required to maintain safety. The panelists spoke of successes in the field with redundant transportation and monitoring systems such as the Fireguard notification system which successfully monitored and mapped fire perimeters every ten minutes during an incident. In contrast, the panelists had experienced operational failures from difficult to predict structure-to-structure ignition; unintended consequences of advanced technology, such as 5G boosters; lack of data unity leading to confusion; and a disconnect from actual risk due to premature trust and reliance on new technology. Throughout the discussion, panelists gave special attention to predictive models and artificial intelligence limitations, information services, and data dissemination.

The panelists agreed that on-board UAS capabilities have endless possibilities, including on-board data processing, prediction capabilities, and artificial intelligence. For example, advanced on-board sensors could be used to collect and monitor real-time weather data. To develop useful artificial intelligence capabilities, problem sets must be carefully defined with solutions developed through close collaboration between designers and wildfire management. Artificial intelligence and predictive capabilities must be extensively trained using real-time data, legacy data, and other validated models if necessary. Even when trained thoroughly, these capabilities will operate in complex, highly variable systems and will produce predictions and outputs with some uncertainty. A shift from restrictive complexity, which aims to control complexity in systems, to general complexity, or the acceptance of the unexpected, is recommended to shift towards sense-making models centered on observing system behavior. Across the panelists, the discussion highlighted a need for defining problems thoroughly with stakeholders to produce meaningful solutions, extensive data requirements for training autonomous systems, leveraging UAS for advanced modeling from real-world data, and shifting to understand system outputs in the context of general complexity.

***Data and information dissemination from services is a challenge area.*** Panelists were concerned with the susceptibility to information overload as well as the need for real-time data. While personnel need real-time, curated information delivered, a crew boss and firefighter have different information needs. Another challenge is delivering consistent data to personnel from various organizations and career levels. Suggestions included curated or filtered data, geo-spatial displays, artificial reality displays, and integrated applications for consistent data. One identified opportunity was enhanced data products for assessing the efficacy of fire suppression actions. That is, measuring response effectiveness by identifying areas where fire lines and retardant drops are successful, rather than just quantifying the amount of fire line built per day. Ultimately, the panel agreed that advanced systems providing information services should provide consistent, real-time data curated to the personnel role to prevent information overload while providing vital information.

Panelists discussed barriers to implementing novel technologies, such as autonomous systems and advanced data services, in wildfire response. The panelists agreed that ***bureaucracy is a large barrier*** and prevents technology (like UAS) from getting implemented in a timely manner. Getting research concepts into operations is difficult but programs such as NASA's SBIR and STTR are useful for moving developmental concepts into real world operations. While technology exists to address some issues, the technology does not scale in disconnected environments and certification may take a long time. ***Autonomous systems often need large amounts of bandwidth for sensing in initial attack and early detecting operations, which inhibits their use in the limited bandwidth environment*** inherent to wildfire response. Developing a collaborative technology testing center and using supplemental service providers may alleviate these challenges. The ***believability of the concept and its products are also barriers;*** developing trust in the performance and safety of novel technology is vital to implementation. Another challenge is shifting to sense-making from decision-making. Currently, people are expected to learn new concepts from experience, but instead a panelist proposed moving towards developing beneficial improvisation and sense-making models as a learned capacity (e.g., learning via exploration in new situations).

### 3.3.2. Day 3 Breakout Sessions

The Day 3 breakout sessions focused on identifying safety risks and threats that are experienced during wildland firefighting, identifying relevant precursors, and identifying possible methods to recognize or address these risks more effectively. Approximately 50 participants from more than 40 agencies spanning government, industry, and academia separated into four breakout rooms. (See Appendix D for a list of participating groups.) Following is a distillation of the information received during these breakout sessions.

#### *3.3.2.1. Safety Risks and Other Threats in Wildland Firefighting*

Breakout room moderators asked workshop participants to name common safety risks they experience during wildland firefighting. One of the most common safety-impacting factors participants named was a ***lack of standardization in operating procedures and responsibility hand-off*** between local, state, tribal, and federal firefighting groups. While these groups may have similar goals when it comes to suppressing wildfires, the differences in funding, stakeholder value priorities, data and technology access, and pre-season planning information factors cause a great deal of friction when these groups must interact. This friction, especially when augmented by pressure from local citizens and other stakeholders, can result in miscommunication, among other issues, during active firefighting that directly impacts safety.

Participants also identified ***unfamiliarity with available technology*** as another potential safety risk source. As firefighting procedures are ingrained over years of repetition and reinforcement, firefighters must undergo extensive training to unlearn old habits and adopt a new technology. This requires time and money, both of which are in short supply for many firefighting organizations. By foregoing such crucial training, organizations run the risk of inadequate understanding of operational requirements for new technology and the technical maturity and operational costs involved in adoption.

***Climate change*** is also a safety risk source due to weather pattern volatility, fuel conditions, and the expansion of neighborhoods into wildfire-prone areas. As conditions change over decades, new fuel sources become available, old fuel sources burn differently, and fire behavior becomes more difficult to predict and control. This increases the threat of firefighters losing situational awareness during their suppression activities. Remote wildland fires pose an additional risk; locating a new fire in a remote area can be difficult due to high winds, insufficient satellite imagery, and smoke from pre-existing fires.

#### *3.3.2.2. Precursors of Safety Risks*

Workshop participants identified several precursors which may precipitate safety risks in fighting wildland fires. Organizations rely heavily on interpreting established weather patterns, though ***climate variability*** makes interpreting the true impact of regional monthly and daily conditions more difficult. Additionally, organizations compile lessons learned checklists from previous incidents with particular attention paid to conditions which contributed to losing situational awareness.

Participants stressed, however, that certain aspects of the ***firefighting culture*** can also contribute significantly to safety risk. For example, firefighting crews may be asked to perform tasks they are not comfortable executing, such as deploying to protect assets of contentious value to different stakeholders. Such deployments are typically assigned by higher level leadership without allowing ground crews to refuse. If ground crews do feel comfortable refusing these assignments, the responsibility is typically transferred to aerial units, whose operation carries its own risk. Participants agreed that ground crews rely heavily on the expertise and authority of the incident commander to understand local stakeholders' needs and risk priorities.

Participants also identified a ***lack of common understanding*** of both standard operating procedures and restrictions as a breeding ground for potential safety risk concerns. This includes a lack of understanding between firefighting agencies and the public. For example, participants have observed communications difficulty between firefighting and law enforcement crews due to infrastructure differences; residents were generally unaware of "carding" (i.e., licensing and certification) restrictions requiring that every pilot and aircraft involved in a federal wildland firefighting operation be vetted and authorized to fly over federally managed lands[6].

#### *3.3.2.3. Challenges in Identifying Safety Risks*

Workshop participants also named several challenges preventing safety risks identification. These challenges generally fell into one of two categories: ***cultural or technological***. Participants cited communication and coordination barriers between groups as common cultural challenges. These barriers exist due to such factors as mismatched funding and procedural priorities between firefighting agencies, a lack of cultural and value awareness with indigenous populations, and a lack of general education and understanding with the public at large. This challenge is further exacerbated by a ***lack of common standard operating procedures*** between local, state, tribal, and federal firefighting authorities.

The most frequently mentioned technological challenges include: difficulties in acquiring and sifting through data, modelling fire behavior, and disseminating key insights for situational awareness back out to firefighting crews. Participants emphasized particular difficulty in obtaining accurate fire behavior predictions at the local level due to changing climate, human impact, and data volume and quality required.

[6] https://www.nwcg.gov/committee/6mfs/aviation/aircraft-and-pilot-carding

#### *3.3.2.4. Suggested Methods for Recognizing and Mitigating Safety Risk*

Workshop participants suggested several methods for procedural and technological improvements to better recognize and mitigate safety risk. The loudest call was for ***improved data connectivity and communications infrastructure*** that increases and synchronizes situational awareness during active fire suppression across all personnel tiers. Throughout the workshop, participants cited a ***lack of situational awareness*** as the root cause for many threats to both firefighter and public safety, such as engaging in suppression activities with an unrealized low probability of success due to outdated or an overabundance of data. Primary suggestions to improve situational awareness included incorporating ***robust and resilient radio-based platforms for communications, data sharing, and interoperability*** between tribal, local, state, and federal decision makers; ***data aggregation platforms which ingest, clean, and synthesize disparate data streams*** from different systems in order to report back to crew bosses with situationally relevant insights; and to ***incorporate artificial intelligence and machine learning*** to continually evaluate and improve fine-grained fire behavior models. It was noted that NWCG[7] and NIFC[8] have initiated committees and resources to begin to address these types of needs, but such efforts are still in their preliminary stages.

Participants also identified ***communication with and education of the public*** as major improvement opportunities, including a desire for generally improved public knowledge on firefighter tools and data, their applications, and how they are used to make decisions. Additional public education opportunities include understanding the true consequences of living in a wildfire-prone area; the impact of climate change and neighborhood expansion on the wildfire proneness of an area over time; and how active wildfires impact infrastructure availability. Participants hope that investing in public education in these areas increases trust in the government and local authorities to evaluate and respond to active fire incidents, particularly as it related to evacuation orders.

Throughout the session, participants suggested an array of supplemental approaches to identifying and mitigating risks more effectively. Such suggestions included ***improving the "carding" process*** for pilots and aircraft in federal firefighting scenarios as the process is very slow, expensive, and difficult to complete even though there is a "critical shortage of aerial resources" for wildland firefighting. Participants also indicated a need for tools and procedures for ***better understanding the emotional, physical, and cognitive burden on firefighters*** when engaging in extended suppression activities. Additionally, developing larger scale standard operating procedures such as the State of Wyoming's "Wildfire Management Annual Operating Plan" was mentioned (USDA Forest Service, 2018) as a potential avenue. Finally, participants stressed the need for ***better testing sandboxes*** (i.e., isolated testing environment) specifically related to firefighting agencies' ability to evaluate tools and technologies developed by small businesses. This market was mentioned because small businesses struggle to protect intellectual property once it goes public and firefighting agencies may not have the funding or resources to commit to a product without proof that it will meet their needs. The U.S. Forest Service is working on a set of standards to guide such collaborations as well as the acquisition and adoption of new technology.

---

[7] https://www.nwcg.gov/committees/data-management-committee

[8] https://data-nifc.opendata.arcgis.com

## 4. Analysis and Summary of Findings

As the workshop progressed and the inputs were analyzed, several recurring themes began to emerge that were common across all three days. Of note, and rarely stated as such, many challenges mentioned were human factors challenges: issues of training and standardization, staffing, leadership, teamwork, communication, performance in the design of interfaces, situational awareness, along with others. In aviation, as well as other forums, these are the precursors to safety-critical decision making and performance. As solutions are explored, both in the aviation context and beyond, appropriate consideration of human performance principles should be considered as they are critical to enabling safe wildland firefighting operations.

A key recurring concern was enhancing the situation awareness of wildland firefighting agents in the field, and across the entire operational picture. Active fire risk evaluation concerns included three elements: (1) Where is the fire now? (2) Where is it going? and (3) What are the agents and assets in its path? As wildland firefighting operations are widespread, ground agents must make their own safety-critical decisions, aided by information received from aviation and space-based assets. It is imperative that the right information is given to the right agent to make a safety-critical decision in a timely fashion. The potential cost-effective deployment of aviation assets to enhance current information sources and augment situation awareness in the field is an area of interest.

Participants and panelists emphasized the need to manage information agents receive in wildland firefighting operations in terms of its type, quality, and quantity. Accidents frequently trace to insufficient information availability (availability); out of date information (latency); or incorrect, inaccurate, or incomplete information (validity and correctness). Participants cited a lack of communications infrastructure and bandwidth as key challenges to getting safety-critical, timely information in the field. Additionally, maintaining an accurate picture as to the state and deployment of aerial assets (both manned and unmanned) is critical to ensuring the safety of the operation.

Furthermore, field agents had difficulty interpreting information once received. A wildland firefighting agent must fuse together multiple, diverse sources to gain a full picture of the operational landscape. These sources are often found on disparate websites or paper maps, which can make information difficult to locate and the superimposed visualization of this information is non-trivial to synthesize. Additionally, in high-risk scenarios it is important that the wildland firefighting agents be able to filter out unnecessary information so that they can adequately assess their own risk. The ability to layer and customize information to fit the task and context at hand is a key safety gap in current wildland firefighting practices. This concern is also applicable to the visualization of the state, operational intent, and health of aerial vehicles deployed during wildland firefighting missions.

Since wildland firefighting is a dynamic, distributed operation, achieving shared situational awareness through a common operating picture is essential. Operational system safety is an emergent property: safety-critical decisions made by individual agents can impact other safety decisions and thus cannot be made in isolation. Moreover, prolonged wildland firefighting operations require multiple agencies across all levels of government to coordinate with one another to ensure efficient asset and personnel deployment. Local first response units often lead the wildland firefighting effort in the initial attack phase. Coordinated state and federal responses and organizational structures may dominate the extended attack phase. Thus, responsible parties must carefully manage transitioning safety critical roles and responsibilities between these phases to ensure there are no lapses. Lack of interoperability of resources and procedures may also hinder a common operational view and optimal resource allocation, a concern which is especially true in the use of limited aerial assets. The use of tailorable, open standards would render equipment and data more readily available across all phases of the wildland firefighting operation and enhance the formation of a common operating view by meshing operational procedures across all levels of government (e.g., federal, state, local, and tribal). This may also enhance communication and coordination between organizations whose interests may not be perfectly aligned with one another thereby reinforcing safety culture and safety management systems.

Additional concerns include barriers to the timely transition of research into the successful, ruggedized field deployment of the technology. This is a socio-technical gap relevant to incorporating safety-enhancing advances into wildland firefighting operations. NASA is currently, through the STEReO initiative, trialing efforts to address this issue using specific technologies that enhance situational awareness. Intensive training requirements for new technologies makes these technologies more difficult to incorporate. Moreover, the lack of strategic community engagement and dissemination of information to the public is a significant barrier to safety. Increasing coordination with communities in and near the wildland firefighting area during the incident and educating communities on common practices to lower fire risk (e.g., eliminating ignition sources, etc.) are opportunities to lower risk throughout the wildfire management lifecycle. Wildland firefighting culture may also present an opportunity to increase safety margins; overcoming a high-risk/high-reward mindset may improve operational safety.

## 4.1. Top Three Findings from the Workshop

- Enhancing situation awareness is a safety priority. This is vital in managing aerial missions in order to ensure operational safety.
    - Getting the right information to the right decision makers at the right time is essential to enhancing operational safety and for enabling a common operating picture.
- Timely access to information that can be consolidated, integrated, and displayed would enhance safety-critical decision-making. The safety of integrated manned and unmanned operations relies on the fusion of timely, accurate information from diverse data sources.
    - Localized data fusion, along with information about data sources and data quality issues that allow layered approaches to the display of information based on context is vital.
- Tailorable standards and a common operating picture (especially in the field) would enhance inter-agency cooperation in the wildland firefighting lifecycle. Uniform standards for the safe deployment of aerial assets would optimize their usage in operations.
    - Open standards would enhance safety, flexibility, and data and asset accessibility.

## 5. Possible Next Steps

### 5.1. Partnerships

A goal of the workshop was to help foster connections and identify opportunities for improving safety throughout the wildland fire management lifecycle. NASA seeks to engage with the wildland firefighting ecosystem through a variety of avenues, including workshops, subject matter expert interviews, and tabletop exercises, where areas for collaboration or leveraging expertise may be identified. NASA can then engage with potential partners via a diverse set of instruments, including Space Act Agreements, Interagency Agreements, the SBIR and STTR programs, and NASA Research Announcements (NRA). NASA is seeking meaningful, long-term partnerships to enhance the impact of any safety improvements to the overall wildland firefighting community.

### 5.2. Safety Demonstrator

The workshop outcomes will help define the first of a series of operationally challenging demonstrations known as the Safety Demonstrator Series for NASA's SWS project. The Safety Demonstrator series is a set of demonstrations tailored towards enhancing the operational safety of disaster-oriented operations. The first safety demonstrator is set in the wildland firefighting application domain, and this demonstrator will: (1) examine high risk operational scenarios to reduce their overall risk via services, functions or capabilities that act as risk mitigators (or transfer that risk to agents better able to tolerate it); and (2) explore novel tools and technologies that will enhance safety margins by enabling non-traditional or neoteric operational paradigms.

The Safety Demonstrator aims to exercise services, functions, and capabilities in a wildland firefighting scenario to: (1) reduce risk associated with safety-critical decision-making; (2) enhance situation awareness to achieve a common operating picture; and (3) identify commonalities to enhance open standards in an in-time aviation safety management system. The scenarios for the wildland firefighting demonstration are currently under development with the help of subject matter experts identified through this workshop and other sources. An example scenario might explore integrated manned/unmanned aerial operations for persistent asset surveillance and wildfire suppression during the extended attack phase, where an (intruder) aircraft enters the TFR airspace without notifying proper authorities.

NASA's Safety Demonstrator series will be closely coordinated with complementary efforts currently underway at NASA, including efforts by the SMD to identify information, modelling, prediction, and analysis gaps and needs for wildland firefighting. Coupling monitoring requirements with safety enhancing technologies (e.g., weather modelling, prediction, and validation via UAS, etc.) presents an opportunity to utilize their synergy and increase system efficiency. Similarly, collaboration with NASA's Advanced Capabilities for Emergency Response Operations (ACERO) project will be a key feature going forward due to the shared wildland firefighting operational use case under study.

## 6. Closing Remarks

NASA's SWS Wildland Firefighting Workshop helped to identify several key safety needs in the broader wildland fire management lifecycle. NASA's role in the wildland firefighting ecosystem along with its traditional areas of expertise may allow NASA to focus on: (1) enhancing safety through improvements in situation awareness; (2) managing information flows to enable safety-critical decision making in a timely manner; and (3) providing a forum for wildland firefighting ecosystem stakeholders to discuss open standards for operational safety improvements.

## 7. References


Andreeva-Mori, A., Kubo, D., Kobayashi, K., Okuno, Y., Homola, J. R., Johnson, M., & Kopardekar, P. H. (2020). Supporting disaster relief operations through UTM: Operational concept and flight tests of unmanned and manned vehicles at a disaster drill. In *AIAA Scitech 2020 Forum* (p. 2202). https://doi.org/10.2514/6.2020-2202

Department of the Interior and Department of Agriculture. (2022). *Interagency Standards for Fire and Fire Aviation Operations* (NFES 2724). Interagency Standard for Fire and Fire Aviation Operations Group, National Interagency Fire Center, Boise, ID. https://www.nifc.gov/sites/default/files/redbook-files/RedBookAll.pdf

FAA. (2020). *Unmanned Aircraft Systems (UAS) Traffic Management (UTM) Concept of Operations v2.0*. https://www.faa.gov/uas/research_development/traffic_management/media/UTM_ConOps_v2.pdf

Flight Safety Foundation. (2021). *Looking to the Future: Safety System Needs for Humanitarian UAS Operations*. https://flightsafety.org/wp-content/uploads/2021/07/D6-DMFR-FINAL.pdf

Green, D. (2021). NASA disasters program: Earth observation for actionable knowledge. In *2021 IEEE International Geoscience and Remote Sensing Symposium IGARSS* (pp. 1709-1710). IEEE. https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=9555114

Kopardekar, P. & Grindle, L. (2021). NASA ARMD Wildfire Management Workshop. https://nari.arc.nasa.gov/sites/default/files/attachments/NASA%20ARMD%20WILDFIRE%20MANAGEMENT%20WORKSHOP_6.1.2021_v13.pdf

Martin, L., Arbab, Y., & Mercer, J. (2021, October). Initial exploration of STEReO (Scalable Traffic management for Emergency Response Operations) system user requirements for safe integration of small UAS. In *2021 IEEE/AIAA 40th Digital Avionics Systems Conference (DASC)* (pp. 1-8). IEEE. https://ieeexplore.ieee.org/abstract/document/9594419

Mercer, J. (2021). *Scalable Traffic management for Emergency Response Operations (STEReO) system, version 1.0 concept document*. Internal report submitted to NASA Convergent Aeronautics Solutions (CAS) Project: unpublished.

Mooberry, J., Reeser, R., Yang, M., Millam, M., & Kirkman, D. (in press). *Updated Operational Scenarios based on Disaster Management and First Responder Project Community Input and Validation* (NASA Contractor Report 80NSSC20M0248).

NASA. (2022). NASA Science Mission Directorate (SMD) Wildfire Stakeholder Engagement Workshop: Summary and Key Findings. Draft Report. https://nari.arc.nasa.gov/sites/default/files/attachments/NASA%20SMD%20Wildfire%20Stakeholder%20Workshop%20Summary_DRAFT.pdf

National Wildfire Coordinating Group. (2013). Wildland Fire Incident Management Field Guide. Accessed June 24, 2022. Website: https://www.nifc.gov/nicc/logistics/references/Wildland%20Fire%20Incident%20Management%20Field%20Guide.pdf

Robinson, J., Johnson, M. J. J., Kopardekar, T., Prevot, & Rios, J. (2015). Unmanned Aerial System Traffic Management Concept of Operations (v0.5)(UTM CONOPS). (NASA TM draft). Moffett Field, CA.

USDA Forest Service (2018). Wildland Fire Management Annual Operating Plan. (Report no. 583752). https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd583752.pdf

Wildfire Lessons Learned Center. (2021). 2021 Incident Review Summary. https://www.wildfirelessons.net/HigherLogic/System/DownloadDocumentFile.ashx?DocumentFileKey=ada90ef9-e019-6d23-d28b-ab92c63a0fd3&forceDialog=0.

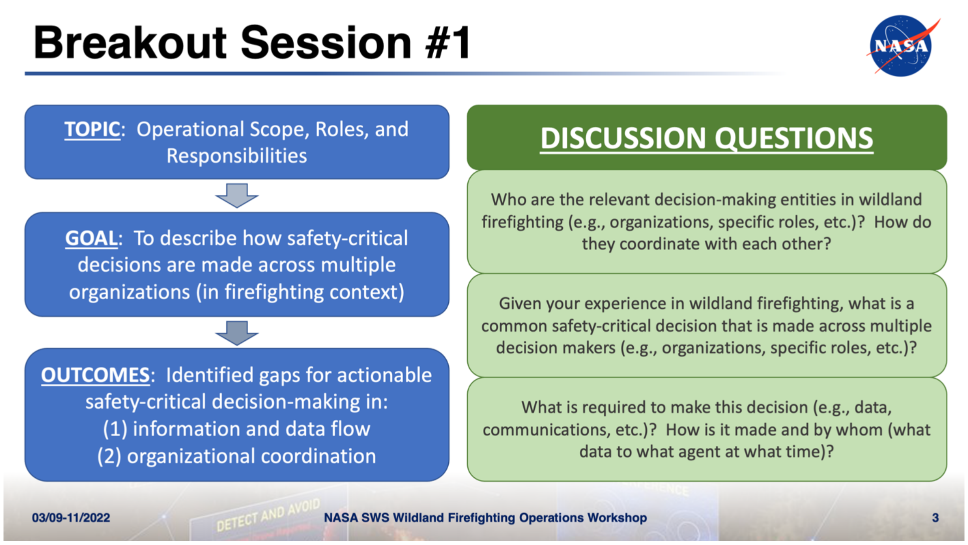
# Appendix A: Agendas

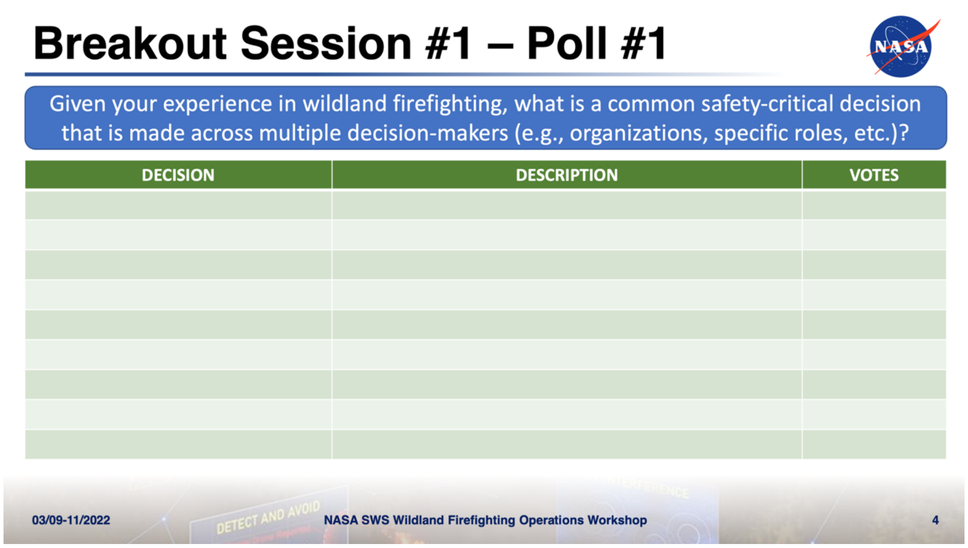
| DAY 1<br>WEDNESDAY, MARCH 9, 2022<br>OPERATIONAL SCOPE, ROLES AND RESPONSIBILITIES | | | | |
|---|---|---|---|---|
| **Time (PST)** | **Time (EST)** | **Topic** | **Speaker(s)** | **Location** |
| 9:00AM – 9:05AM | 12:00PM – 12:05PM | **Welcome** | *Steven Clarke, NASA* | YouTube |
| 9:05AM – 9:15AM | 12:05PM – 12:15PM | **Workshop Goals & Objectives** | *Summer Brandt, NASA* | |
| 9:15AM – 9:30AM | 12:15PM – 12:30PM | **Airspace Operations Safety Program Wildfire Efforts** | *Cheryl Quinn, NASA* | |
| 9:30AM – 10:30AM | 12:30PM – 1:30PM | **Speaker Panel – Organizational Safety and Safety Roles**<br><br>*Moderator: Evan Dill, NASA* | • *Dani Doyle, State of Colorado*<br>• *Brad Koeckeritz, DOI*<br>• *Sashi Sabaratnam, UC Cooperative/County of Sonoma*<br>• *Geoff Marshall, CalFire*<br>• *Sean Triplett, USDA*<br>• *Michael Pavolonis, NOAA* | |
| 10:30AM – 10:45AM | 1:30PM – 1:45PM | BREAK – TRANSITION TO BREAKOUT ROOM | | |
| 10:45AM – 1:00PM | 1:45PM – 4:00PM | **Breakout – Operational Scope, Roles and Responsibilities** | *Moderators: NASA Concurrent sessions pre-assigned* | MS Teams |

| DAY 2<br>THURSDAY, MARCH 10, 2022<br>STANDARD AND EMERGING OPERATIONAL PROCEDURES | | | | |
|---|---|---|---|---|
| **Time (PST)** | **Time (EST)** | **Topic** | **Speaker(s)** | **Location** |
| 9:00AM – 9:10AM | 12:00PM – 12:10PM | **Welcome** | *Natasha Neogi, NASA* | YouTube |
| 9:10AM – 9:30AM | 12:10PM – 12:30PM | **STEReO** | *Robert McSwain, NASA* | |
| 9:30AM – 10:30AM | 12:30PM – 1:30PM | **Speaker Panel – Standard and Emerging Operational Procedures**<br><br>*Moderator: Jon Holbrook, NASA* | • *Mark Bathrick, DOI (ret.)*<br>• *Richard Fields, City of LA Fire*<br>• *Dirk Giles, USDA/Forest Service*<br>• *Coitt Kessler, DroneSense*<br>• *Chris Tubbs, Southern Marin Fire Department*<br>• *Charles Werner, DroneResponders* | |
| 10:30AM – 10:45AM | 1:30PM – 1:45PM | BREAK – TRANSITION TO BREAKOUT ROOM | | |
| 10:45AM – 1:00PM | 1:45PM – 4:00PM | **Breakout – Standard and Emerging Operational Procedures** | *Moderators: NASA Concurrent sessions pre-assigned* | MS Teams |

| DAY 3<br>FRIDAY, MARCH 11, 2022<br>PRIORITIZED RISKS | | | | |
|---|---|---|---|---|
| **Time (PST)** | **Time (EST)** | **Topic** | **Speaker(s)** | **Location** |
| 9:00AM – 9:05AM | 12:00PM – 12:05PM | **Welcome** | *Summer Brandt, NASA* | YouTube |
| 9:05AM – 9:45AM | 12:05PM – 12:45PM | **A Conversation with NASA Leadership on the Wildland Firefighting Ecosystem**<br>*Moderator: Jessica Nowinski, NASA* | • *Parimal Kopardekar, ARMD*<br>• *Misty Davies, SWS*<br>• *Barry Lefer, SMD*<br>• *Jason Kessler, STMD* | |
| 9:45AM – 10:45AM | 12:45PM – 1:45PM | **Speaker Panel – The Art of the Possible**<br>*Moderator: Natasha Neogi, NASA* | • *Don Berschoff, TruWeather Solutions*<br>• *Everett Hinkley, USDA/Forest Service*<br>• *Ivan Pupulidy, UAB*<br>• *Matt Quinn, Great Lakes Drone Company*<br>• *Anthony Schultz, ESRI* | |
| 10:45AM – 10:55AM | 1:45PM – 1:55PM | BREAK – TRANSITION TO BREAKOUT ROOM | | |
| 10:55AM – 1:00PM | 1:55PM – 4:00PM | **Breakout – Prioritized Risks** | *Moderators: NASA*<br>*Concurrent sessions pre-assigned* | MS Teams |

## Appendix B: Breakout Questions



# Breakout Session #2

**TOPIC**: Standard and Emerging Operational Procedures

**GOAL**: To capture the features of a "routine" (not perfect) day, and identify when operating procedures (do not) work

**OUTCOMES**: Documented features of effective vs. poor operating procedures, and supporting rationale

## DISCUSSION QUESTIONS

- From your wildland firefighting experience, can you describe "features" (e.g., common knowledge briefings, accurate maps, harmonized comms, etc.) that are common across a "routine" day of operations?
- Are there standard procedures for "normal" days? When do they work well? How do these procedures support things going well?
- When are there challenges in following operating procedures (e.g., challenges in enacting good habits, etc.)? What do you do to address these challenges? Are there particular recurring challenges?
- How might you address a recurring challenge (e.g., cultural work-arounds, more / less actionable data, new / better procedures, better communications, prediction tools, etc.)?



# Breakout Session #2 – Poll #1

Which feature across a "routine" day of operations has the biggest safety impact?

| FEATURE | DESCRIPTION | VOTES |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |



# Breakout Session #2 – Poll #2

What are the biggest challenges in following / adhering to operating procedures (e.g., challenges in enacting good habits, challenging environments, etc.)?

| CHALLENGE | DESCRIPTION | VOTES |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |

# Breakout Session #3

**TOPIC**: Prioritized Risks

**GOAL**: To prioritize common risks / "bad things that happen", and explore opportunities for safety improvement

**OUTCOMES**: Lists of identified and prioritized risks, and recognized safety opportunities

**DISCUSSION QUESTIONS**

- What risks / "bad things" have you encountered in your experience during a wildland firefighting operation? (List and vote to prioritize.)
- Were there any signs that indicated that this risk / "bad thing" was present before you experienced it (e.g., data, informational cues, precursors, leading indicators, etc.)?
- What made it hard to recognize that the risk / "bad thing" you experienced was present (e.g., no cues, data didn't get to the right person, data indicated multiple different potential situations, etc.)?
- Is there any one thing (e.g., data, tools, operational procedures, etc.) that would have helped you either to: (1) identify the risk / "bad thing" earlier, or (2) address the risk / "bad thing" better?



# Breakout Session #3 – Poll #1

What risks / "bad things" have you encountered in your experience of wildland firefighting operations?

| RISK | DESCRIPTION | VOTES |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |

## Appendix C: Speaker Biographies

**Mark Bathrick** recently retired from the U.S. Department of the Interior where he served for 16 years as Director, Office of Aviation Services (OAS). As the Director, he was responsible for management of all U.S. Department on the Interior aviation operations nationwide, encompassing 66,000 flight hours and involving 20,000 employees. He oversaw four offices across the U.S. and managed over 1,200 traditional and 850 remotely piloted aircraft, supporting critical government missions, such as wildland firefighting. Prior to the OAS, Mr. Bathrick completed a distinguished career as a decorated Naval Aviator, retiring as a Captain. He is currently consulting for Bathrick Aviation Consulting.

**Don Berschoff** is the CEO and founder of TruWeather Solutions with decades of experience in meteorology and Air Force weather monitoring. TruWeather Solutions is a weather risk management and analytics company that has a proven framework for reducing weather's impact on businesses to preserve people and property. Mr. Berschoff is well versed in autonomous systems, weather sensors, data fusion and decision insights where the weather margins are tight and attention to weather detail is paramount for safe, effective and efficient operations.

**Dani Doyle** is a Multi Mission Aircraft Manager for Colorado Division of Fire Prevention and Control where she's flown over 1,300 hours in fixed wing aircraft collecting and sharing critical fire intelligence. Ms. Doyle's passion for wildland fire began in 2004 working on various U.S. Forest Service crews, including hotshots and helicopter rappelling. In 2016, she joined the State of Colorado's bold pursuit using technology in innovative ways to enhance safety of firefighters.

**Richard Fields** established the Los Angeles City Fire Department (LAFD) UAS Program in 2015 and continues to lead the only major public safety agency to possess a jurisdictional Certificate of Authorization from the FAA. The LAFD has emerged as a public safety leader in developing and integrating UAS technology in the fire service. Chief Fields represents the LAFD and serves in advisory and working group capacities for the FAA, NASA, and Homeland Security.

**Dirk Giles** is the UAS Program Manager for U.S. Forest Service. He has worked in wildland firefighting and aviation for 24 years with much of his time on hotshot crews based in Alaska.

**Everett Hinkley** is the National Remote Sensing Program Manager for the U.S. Forest Service. Mr. Hinkley provides remote sensing program guidance and coordination to the Forest Service field units throughout the U.S. and serves as the remote sensing liaison to other federal and state agencies. He has led successful efforts to improve fire detection and reporting using space-based Earth observation capabilities.

**Coitt Kessler** recently retired from the Austin Fire Department after 21 ½ years with the organization. For the last eight years he was the Program Manager for Robotic Emergency Deployment Team. He currently works for DronseSense.

**Brad Koeckeritz** has worked in fire and aviation since 1992. He spent the first part of his career working on a variety of helitack crews across the western U.S., having served as the crew supervisor on the Teton Helitack crew providing fire and search and rescue services for the Bridger-Teton National Forest and Grand Teton National Park. Mr. Koeckeritz joined the U.S. Department of the Interior's OAS in 2009 and has been involved fill-time in the UAS integration since 2010. In his current role he oversees the UAS program which includes over 450 remote pilots and over 900 UAS.

**Geoff Marshall** is the Chief of Predictive Services for the California Department of Forestry and Fire Protection (CAL FIRE) where they predict near- and far-term fire potential for seasonality based on fuel and weather. This is Chief Marshall's 23rd fire season, and he has worked his way through the ranks as a firefighter, dabbled on engines, spent time in aviation, and currently works fire behavior analyst activities gathering and providing intel to executives for higher level decisions.

**Mike Pavolonis** is the Manager of the Fire Product and Service Program as part of the National Environmental Satellite Data and Information Service within the National Oceanic and Atmospheric Administration (NOAA). While NOAA is not a firefighting or land management agency, NOAA does provide support and protection of life and property throughout the wildfire management lifecycle, be it through an incident meteorologist, provision of spot forecasts, satellite observations or other types of observations modeling fire weather forecasts.

**Ivan Pupulidy** is a former Director of the Office of Innovation and Organizational Learning for the U.S. Forest Service where he was responsible for a team of practitioners, researchers and subject matter experts who developed Learning and Resilience protocols for strategic, tactical, individual and organization applications. Dr. Pupulidy developed the U.S. Forest Service Learning Review Process which provides guidance for organizational review of serious accidents. He is a former Coast Guard aviator and current professor at the University of Alabama at Birmingham.

**Matt Quinn** is the CEO of Great Lakes Drone Company in Michigan. The company is a Part 107 certified UAS provider of media services with specialties ranging from aerial photography and night-flight, multi-UAS drone light shows to search and rescue and emergency services. He has experience as a firefighter and paramedic for the past 20 years.

**Sashi Sabaratnam** has a diverse background in research, policy, and practice with the goal of setting up wildfire prevention for success. She is the program manager of the UC Cooperative Extension Wildfire Vegetation Mitigation Division for the County of Sonoma. She is also a councilmember in the City of Mill Valley in Marin County, CA, a founding board member of the Marin Wildfire Prevention Authority, and is attending the Naval Postgraduate School Master's Program for the Center of Homeland Defense and Security, with a focus on wildfire prevention.

**Anthony Schultz** is the Director of Wildland Fire Solutions at Environmental Systems Research Institute. Mr. Schultz is a former firefighter and previous Fire Management Officer for the State of Wyoming where he managed suppression operations and cooperative fire programs.

**Sean Triplett** is the Tools and Technology Team lead for the Forest Service Fire & Aviation Program located in Boise, Idaho at the National Interagency Fire Center. He manages a diverse portfolio of programs that focus on geospatial and data integration technologies to support wildland fire fighters and decision makers.

**Chris Tubbs** is the Fire Chief for the Southern Marin Fire Department and is responsible for managing their participation in the California Mutual Aid System as well as the provision of all their services at the local level. Chief Tubbs serves on the operations committee and several ad hoc committees of the of the JPA which exists to reduce the risks from wildland fire in Marin County.

**Charles Werner** is a retired Fire Chief from Charlottesville, VA where he spent 37 years with the Charlottesville Fire Department. He then spent two years as a Senior Advisor and Acting Deputy State Coordinator with the Virginia Department of Emergency Management. In 2019, Chief Werner started an organization called DRONERESPONDERS to create a network to advance the use of public safety UAS. The organization has over 5,000 members from 73 countries and hosts a dashboard that has over 1,000 agencies sharing information about their programs.

## Appendix D: Workshop Registrant Organizations

4SPACE, LLC
Advanced Mobility Collective
Airbus
Akin Gump
American Aerospace Technologies, Inc.
Ann Walker Consulting LLC
Arbonaut, Ltd.
Arizona Department of Forestry and Fire Management
Arkansas Department of Agriculture, Forestry Division
ASTERRA
Auterion
Bathrick Aviation Consulting LLC
Bay Area Environmental Research Institute
Bintel, Inc.
Black Swift Technologies
Boston University
Bureau of Indian Affairs
Bureau of Land Management
California Army National Guard
California Department of Corrections and Rehabilitation
California Department of Forestry and Fire Department (CAL FIRE)
California Department of Transportations
California Fire Safe Council
California Geological Survey
California Governor's Office of Emergency Services
California Polytechnic State University
California State Guard
CANA LLC
Carnegie Mellon University
CEiiA
Cherokee Federal
Choctaw Nation of Oklahoma
Civil Air Patrol
Clemson University, South Carolina
Collins Aerospace
Colorado Division of Fire Prevention and Control
Columbia University
Commonwealth Scientific and Industrial Research Organisation
Consolidated Resource Imaging
Cooperative Institute for Research in the Atmosphere
Cornea
Corverity Corporation
County of Tuolumne
Courtney Aviation
Crown Consulting Inc.
Daniel H. Wagner Associates, Inc.
DD Dannar, LLC
Deer Creek Resources
Defense Innovation Unit
Deloitte
Delphire, Inc.
Delta Consortium
Disaster Technologies Inc.
DRONERESPONDERS
Earth Labs Group
Ember Flash Aerospace
Embry-Riddle Aeronautical University
ENPLAN
Environmental Systems Research Institute (ESRI)
European University Cyprus
Federal Aviation Administration (FAA)
Federal Emergency Management Agency (FEMA)
Fireball Information Technologies
Firestorm Wildland Fire Suppression, Inc.
Flight Safety Foundation
Florida Institute of Technology
Future Labs
George Mason University
GIS Surveyors, Inc.
Golden Star Technology (GST)
Great Lakes Drone Company LLC
Improving Aviation LLC
Incaendium Initiative Corporation
Insitu
Intterra
Jackson Family Wines
Joint Fire Science Program
KBR, Inc.
Kettle
Keweenaw Bay Tribal Community
Kitware, Inc.
L3Harris
Lawrence Berkeley National Laboratory
Lincoln Laboratory, Massachusetts Institute of Technology
Lockheed Martin Corporation
Lone Star UAS Center of Excellence and Innovation
Los Angeles City Fire Department

Manitou Springs Fire Department
Marin County Fire Department
Marin Wildfire Prevention Authority
Michigan Technological University
Michigan Tech Research Institute
Monday.com
Modern Technology Solutions, Inc.
Muon Space
National Aeronautics and Space Administration
National Institute of Standards and Technology (NIST)
National Oceanic and Atmospheric Administration (NOAA)
National Park Service
National Research and Innovation Agency
Natural Resources Canada
Near Space Corporation
New Light Technologies
North Carolina Forest Service
Novato Fire District
Oak Ridge National Laboratory
OSGeoLive
Overwatch Imaging
Owyhee Air Research
Parallel Flight Technologies, Inc.
Planet
Power River Energy Corporation
Quest Remote Sensing Analytics
Radius Capital
Rain
Raven Industries, Inc.
Refract Media
ResilienX, Inc.
Resolutions, Inc
Resolute ISR
Rocky Mountain TSG
RoGO Communications
SAIC
San Diego State University
San Jose State University
Scappoose Fire District
Sceye
Skymantics
Skyward, Ltd.
South Carolina Forestry Commission
Southern Marin Fire Protection District
Spatial Informatics Group
SPOTR Industries
Stanford University
State Water Resources Control Board
StormCenter Communications, Inc.
Swift Engineering, Inc.
TESIAC
The Aegis Array LLC
The Analytical Moose LLC
The Boeing Company
The George Washington University
The Hong Kong Polytechnic University
The MITRE Corporation
The University of Texas at Dallas
Toofon, Inc.
Trident Sensing LLC
TruWeather Solutions, Inc.
University of Alabama in Huntsville
University of Alaska Fairbanks
University of California, Berkeley
University of California Cooperative Extension
University of California, Los Angeles
University of California, San Diego
University of Iowa
University of Kansas
University of Maryland
University of Montana
University of Nevada Las Vegas
University of Queensland
University of San Francisco
University of Vermont
University of Wyoming
Unmanned Experts Inc.
USAID
US Department of Energy
US Department of Health & Human Services
US Department of the Interior
US Environmental Protections Agency
US Fish and Wildlife Service
US Forest Service
US Geological Survey
Verizon
Vibrant Planet
Watershed Research &Training Center
West Virginia Division of Forestry
Western Area Power Administration
Western Fire Chiefs Association
Wichita West Volunteer Fire Department
Wildfire Defense Systems
Wildfire Mitigation Services LLC
Wisk Aero
Woolpert
Xiomas Technologies LLC

## Appendix E: Workshop Contributors

| NASA and NASA Contracts* | |
|---|---|
| Abigail Glenn-Chase, SimLabs | Jonathan Nguyen, SimLabs |
| Alan Hobbs, SJSURF | Kyle Ellis, NASA |
| Angela Boyle, Wyle Labs | Laura Bass, TEAMS3 |
| Anna Cavolowsky, NASA | Lauren White, NASA |
| Barry Lefer, NASA | Mallory Graydon, NASA |
| BreeAnn Stallsmith, Wyle Labs | Melinda Gratteau, Wyle Labs |
| Cecelia Town, Logical-R Joint Venture, LLC | Miki Huynh, Wyle Labs |
| Cheryl Quinn, NASA | Misty Davies, NASA |
| Christine Clark, NASA | Moheb Hanna, Axient |
| Cindy Valdez, USRA | Parimal Kopardekar, NASA |
| Daniel Hulse, NASA | Patricia Revolinsky, NASA |
| Dorrit Billman, NASA | Paul Miner, NASA |
| Ersin Ancel, NASA | Peter Mehlitz, KBR |
| Evan Dill, NASA | Robert McSwain, NASA |
| Eve Perchanok, USRA | Robert J. Shively, NASA |
| Garrett Sadler, NASA | Samantha Infeld, AMA |
| James Ackerson, SimLabs | Sepehr Bastami, NASA |
| Jason Kessler, NASA | Steven Clarke, NASA |
| Jessica Nowinsky, NASA | Terry Morris, NASA |
| Jillian Keeler, NASA | Thomas Pressburger, NASA |
| Joel Lachter, NASA | Tyler Fettrow, NASA |
| Jolene Feldman, NASA | Vernol Battiste, SJSURF |
| Jon Holbrook, NASA | |

| External Contributors | |
|---|---|
| Anthony Schultz, ESRI | Geoff Marshall, CAL FIRE |
| Brad Koeckeritz, U.S. Department of the Interior | Ivan Pupulidy, University of Alabama at Birmingham |
| Charles Werner, DRONERESPONDERS | Mark Bathrick, Bathrick Aviation Consulting |
| Chris Tubbs, Southern Marin Fire Department | Matt Quinn, Great Lakes Drone Company |
| Coitt Kessler, DroneSense | Mike Pavolonis, NOAA |
| Dani Doyle, State of Colorado | Richard Fields, Los Angeles City Fire Department |
| Dirk Giles, U.S. Forest Service | Sashi Sabaratnam, UC Cooperative Extension |
| Don Berchoff, TruWeather Solutions | Sean Triplett, U.S. Forest Service |
| Everett Hinkley, U.S. Forest Service | |

* Contract Companies at NASA:
  Analytical Mechanics Associates Inc. (AMA)
  San Jose State University Research Foundation (SJSURF)
  SimLabs III Contract Management & Technical Services (SimLabs)
  Universities Space Research Association (USRA)