Bushfire Research Centre of Excellence

FIRETECH CONNECT

Remotely Piloted Aircraft Systems in Bushfire Management: A NATIONAL ROADMAP

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Foreword

The use of emerging aviation technologies such as Remotely Piloted Aircraft Systems (RPAS) for natural disaster risk reduction purposes in Australia has increased substantially in recent years, with fire and emergency services trialling and integrating these technologies into their bushfire response practices. RPAS have significant transformative potential to improve our resilience against bushfires and other emergencies. Realising this potential will require national coordination between operational agencies as well as research institutions and the industry.

Department of Infrastructure, Transport, Regional Development, Communications and the Arts (DITRDCA) commissioned the ANU Bush Fire Centre of Excellence together with Firetech Connect and CWIFT to prepare this report to provide advice on a pathway to improve national coordination of Australia's drone research and operational capability to support bushfire risk reduction practices.

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Executive Summary

Bushfires cause immense environmental, social and economic harm in Australia every year. The impact of bushfires is substantial and escalating, burdening societies with direct costs, including property loss, firefighting expenses, healthcare cost, insurance claims, and, tragically, loss of life - both directly and indirectly due to smoke inhalation. Together, these direct costs reach tens of billions of dollars annually.

These direct costs, however, are dwarfed by the less quantifiable, but equally significant, indirect costs, encompassing; lost productivity, business disruptions, reduced tourism, declining property values and diminished quality of life. Bushfires degrade vital ecosystems, leading to long-term ecological and economic consequences that extend well beyond the immediate aftermath of the fires. Furthermore, the psychological toll of bushfires is also profound, affecting individuals, families and entire communities with lasting mental health impacts.

Anthropogenic climate change, coupled with urban expansion into fire-prone areas and ageing infrastructure, is projected to exacerbate these costs significantly, demanding a strategic shift in our approach to bushfire management.

The path forward lies in transitioning from a reactive, recovery-centric approach to a proactive strategy that emphasises prevention and resilience. This transition demands innovative solutions and this report explores how the emerging aviation technology of Remotely Piloted Aircraft Systems (RPAS) can provide one of the key enabling technologies for the transformation.

Emerging RPAS technology offers transformative capability across the whole emergency response sector. Amongst the potential capabilities are; comprehensive Intelligence, Surveillance and Reconnaissance (ISR) support before, during and after disaster events, providing communications in remote areas or after damage to infrastructure, as well as enabling scalable transport capability to provide wide area targeted logistical support during and after disasters. RPAS can offer a safer alternative to crewed aircraft for dull, dirty and dangerous tasks in bushfire management, mitigating risks to personnel. Moreover, the inherent scalability of RPAS technology allows systems to be tailored to specific needs and budgets, making sophisticated aerial capabilities more accessible to a wider range of agencies.

Bushfire applications include the whole range of RPAS technology, from small scale quadrotors for localised situational awareness, vehicles for surveillance flights that enable early detection of ignitions and monitoring of active fires, vehicles that support controlled burn activities, through to larger vehicles that could directly suppress fires with water bombing activities or provide targeted logistical support to responders, including specialist responders such as Remote Area Fire Teams (RAFT). Operation over an active fire field will require integration of RPAS technology into shared airspace. **Bushfire management applications provide the ideal testing ground for advancing RPAS technology,** contributing to a robust ‘all hazards' national capability that supports the entire emergency response sector..

Realising the full potential of Remotely Piloted Aircraft Systems (RPAS) will require several challenges to be addressed. Currently, Australia's approach to RPAS integration in bushfire management is fragmented, lacking cohesive national leadership and a clear strategic direction. Key roadblocks include technological readiness of RPAS technology, regulatory barriers in common with any new technology, funding constraints, political considerations, and agency resistance to invest in untested technology. This reluctance stems from the need for RPAS to demonstrate their ability to function reliably and seamlessly within existing bushfire management frameworks. Until these capabilities are demonstrated effectively, agencies may be hesitant to invest in RPAS for bushfire management.

To overcome these obstacles, this roadmap advocates for a collaborative approach, uniting government, fire agencies, industry, and research institutions in a shared vision to achieve seamless integration of RPAS technology into Australia's bushfire management systems. To drive this vision forward, we recommend each State Fire Agency identifies an executive champion to promote RPAS technology adoption and develops high level strategic plans for adoption of RPAS technology. We also recommend establishing a 5 year national technological centre targeted at testing, evaluation, development and support of bushfire RPAS technology, along with a test range facility. This facility would provide companies, fire agencies, research institutes and academia with a space to test, develop, and demonstrate systems capability. This collaborative effort will foster technological innovation in the field, enable effective knowledge sharing and ensure timely translation of RPAS technology into operational use in Australia, ultimately enhancing Australia's bushfire response capabilities and resilience.

We also recommend establishing a national RPAS integration working group empowered to coordinate efforts across the state agencies and streamline regulatory processes, particularly for BVLOS operations. This group would focus on developing standardised frameworks for RPAS operations, training, data management, and airspace integration to ensure interoperability, and operational efficiency. Fostering industry engagement through transparent procurement processes and supporting the growth of a robust RPAS industry ecosystem are also critical components of this approach. Additionally, prioritising research and development in areas such as advanced autonomy, data integration, and new sensor technologies will pave the way for future breakthroughs and enhance RPAS capabilities in bushfire management.

This report outlines a strategic framework for integrating RPAS technology into Australian bushfire management, and by extension the wider emergency management domain, offering a pathway towards a safer and more resilient future. The urgency to act is clear. Through collaboration and commitment, we have the opportunity to make this vision a reality and strengthen our capacity to protect communities and landscapes across Australia.

A DC10 air tanker delivers retardant during the 2020 Black Summer bushfires. (Photo: Gary Hooker)

PART 1: **Overview**

1.1 Background and Context

For decades, aviation has played a vital role in Australian bushfire management. Crewed aircraft have played a critical role providing Intelligence, Surveillance and Reconnaissance (ISR) capability before, during and after fires. They have been used in management of prescribed burns to deploy incendiaries into difficult terrain and provide situational awareness during the burn. Additionally, they provide a water bombing capability that remains a core aspect of fire management in Australia.

The technology for crewed aviation systems is well established and does not change rapidly. The capabilities, risks, and limitations are well understood and existing fire management practices are adapted to exploit the capabilities and limit risk. The most important technological advance in crewed systems in recent years is the adoption of night time flying for ISR and water bombing activities. This capability is still in its infancy and requires special equipment and procedures including night vision goggles (NVGs), laser pointer capabilities, forward-looking infrared (FLIR), as well new procedures including working with two aircraft one of which acts as a spotter to provide better situational awareness [AirMed&Rescue, 2020].

Remotely Piloted Aircraft Systems (RPAS) are an emerging aviation technology that has the potential to complement the aerial capability in Australian bushfire management. RPAS have the potential to significantly enhance existing capabilities while unlocking entirely new applications. They have several key advantages over crewed aviation:

- They do not need to accommodate a pilot and can be built to a scale appropriate for the task considered.
- Many types of RPAS do not require a runway and can be deployed from a wide range of infrastructure.
- They operate by Global Navigation Satellite System guidance and function equally well at night or in limited visibility conditions.
- Since there is no pilot, loss of an RPAS has negligible consequences compared to loss of a crewed vehicle. And since they are generally smaller there is also less risk to bystanders and other operational personnel.

Against these advantages, RPAS come with their own disadvantages:

- They lack situational awareness since they do not have a pilot.
- They do not integrate easily into existing air traffic management systems that are primarily based on ‘see and avoid’.
- Many of the smaller RPAS are built to consumer technology standards and are not sufficiently robust or reliable for operational deployment.

The disadvantages of RPAS are significant roadblocks to their deployment at the present time. This report has strong feedback from current aviation companies that highlight safety and reliability concerns associated with operating RPAS in the same airspace as crewed aviation, especially in the difficult conditions associated with an active fireground.

These issues are not ones that can or should be ignored or minimised, and there is a long road ahead in the potential deployment of RPAS in fire management. New technology and operating procedures are required, and the fire management community must build understanding and trust in the types of vehicles and systems that can be deployed as appropriate technological solutions to the existing roadblocks. Once these roadblocks are addressed, the natural advantages of RPAS offer to significantly enhance existing operations in fire management while unlocking entirely new operational capability.

1.2 Objectives

This roadmap is structured around four key objectives:

Analyse the Current Landscape: Conduct a thorough analysis of current RPAS applications within Australian fire services. This includes identifying existing capability gaps, highlighting operational successes, and pinpointing barriers hindering further integration.

Define Future Potential: Explore and define potential future use cases for RPAS technology in various bushfire scenarios. This exploration will encompass both near-term applications with readily available technologies and long-term visions leveraging advancements in Artificial Intelligence, autonomy, and data analytics.

Prioritise Research and Development: Propose a clear set of research priorities that directly support the development of future use cases and encourage greater uptake of RPAS technologies by fire services.

Empower Policymakers: Develop actionable and evidence-based recommendations for policymakers. These recommendations will provide clear pathways to reduce or eliminate barriers hindering fire services from adopting and integrating RPAS technology into their standard practices.

1.3 Process

This report is the culmination of a six-month collaborative effort between leading researchers in bushfire science and RPAS technology, experienced practitioners in bushfire management, and industry experts at the forefront of RPAS innovation. We began with a comprehensive review of existing literature, analysing academic papers, trial reports, industry surveys, and policy documents. This was followed by an extensive stakeholder engagement phase, conducting in-depth interviews with representatives from land management agencies, state fire services, indigenous communities, RPAS manufacturers, regulatory bodies, and international counterparts.

Draft findings and recommendations were then iteratively reviewed and refined in consultation with key stakeholders, ensuring that the final recommendations reflect a diverse range of perspectives, address real-world challenges, and offer practical solutions tailored to the Australian context.

1.4 Citations

AirMed&Rescue, 2020, “Nighttime firefighting”, https://www.airmedandrescue.com/latest/long-read/nighttime-firefighting.

PART 2: Components of Remotely Piloted Aircraft Systems

Consumer RPAS technology has reached a high level of maturity for small RPAS, while for larger RPAS and RPAS technology the commercial environment is less well developed. The range of applications that commercial RPAS are undertaking is expanding year by year and the world-wide industry is expected to reach $20 billion by 2025, with predictions of $54 billion by 2030 [Zanelli et al, 2023].

Despite the clear success of commercial RPAS technology, there are historical aspects of the technology that shape what is available now, what will become available, and what the challenges for applying this technology to bushfire application will be.

Remotely piloted aircraft systems have also been developed and used in military applications for many years. Long endurance vehicles for ISR such as the General Atomics MQ-9 Predator series of vehicles, and the Northrop Grumman Global Hawk, are mature and reliable technology that have been transitioned into commercial use. The Altair variant of the General Atomics MQ9 specifically developed as a technology demonstrator for the National Aeronautics and Space Administration (NASA), has already been used for wildfire surveillance in the US [Ambrosia 2006]. Although direct integration of military technology into civilian systems is prevented by various treaties and legal restrictions, the companies that develop and supply the underlying technology are developing systems for civilian use cases as the commercial opportunities arise.

It is certainly not true that the appropriate technology for all high value bushfire RPAS applications is available off the shelf now, and there are significant technology developments that need to be invested in over the next five to ten years that are critical to enabling bushfire related applications.

2.1 RPAS: Remotely Piloted Aircraft Systems

A Remotely Piloted Aircraft (RPA) itself is a vehicle consisting of an airframe with avionics and propulsion. However, RPAS never fly independently, even when operating autonomously. There is always a pilot legally in charge of the operation of the RPA for regulatory reasons, even when the pilot is controlling the RPA through a supervisory ground station and the RPA is flying autonomously.

This makes the operational control system, including ground station, communications systems and air traffic management, as important to understand as the vehicle itself. Furthermore, the role of a RPAS is to transport a payload. The nature of the payload, be it a cargo (equipment or suppressant to be dropped on a fire), or an Intelligence, Surveillance and Reconnaissance (ISR) payload such as a camera or LIDAR sensor, is equally as important as the RPA. This leads to three main categories of RPAS technology that are all equally important: **Vehicle, Operational Control, and Payload**.

To these three systems, we consider adding a fourth system; **Data Management**. Data management is especially important in real-time fire scenarios. It facilitates the distribution of data acquired by an RPA to fire control and individual firefighters, and it integrates mission requirements into the operational control of the RPAS. This is a critical aspect of deriving value from the technology. Additionally, data management includes the processing and analysis of data before distribution, ensuring that the raw data is transformed into valuable insights that can inform real-time decisions

2.1.1 Vehicle

CASA classifies RPAS by weight [Transport 2021]. Due to the way the laws of aerodynamics scale, heavy RPAS tend to fly faster, and since they carry more load, fly for longer and fly further. There are, of course, exceptions of RPAS that fly faster (the small FPV racing quads that have top speeds in excess of 100km/h) or longer (hobby micro fixed wing foam construction gliders that can fly for more than an hour). However, the following table provides an indication of working parameters of commercially available RPAS configurations in the standard classes.

RPAS Class	Weight Class	Cruise speed km/h	Flight time h:m	Range km	Wind limit km/h
Micro	< 250g	5-10	00:10	0.8 - 1.6	2.5 - 7.5
Very small	250g-2kg	35-45	00:45	26 - 34	25 - 35
Small	2kg-25kg	50-80	1 - 6	50 - 480	40 - 65
Medium	25kg-150kg	80-120	8	640 - 960	65 - 100
Large	>150kg	120-250	>10	>1200	90 - 190
Converted aircraft	>1000kg	>200	>10	>2000	>150

Overview of RPA classifications by weight, speed, and operational capabilities. Adapted and extended from the CASA definitions [Transport 2021].

There are applications for all categories of RPAS in bushfire applications other than, perhaps, micro RPAS. The smaller vehicles can have significant constraints on range and flight times, but can easily be deployed by individual firecrew units. Very small RPAS, such as typical quadrotors, are appropriate for local unit situational awareness and ISR roles. Small RPAS with longer flight times and better gust response, can be used for more substantive fire ground surveillance roles, eye in the sky, and incendiaries. Medium and larger RPAS must be deployed by trained ground crew with dedicated infrastructure and operated through centralised operations centres, however, they open the door to wide area ISR roles including ignition detection, active fire ISR, pre- and post-fire surveys. The larger RPAS can carry appreciable load and can provide cargo transport and direct fire suppression activities.

Classification of Remotely Piloted Aircraft:

RPA are primarily categorized based on their lift generation mechanisms, which influence their operational efficiency, cost, and suitability for different tasks. Below, we explore five main types of RPAS: multi-rotor, single rotor, powered lift, aeroplane and airship, discussing their advantages, disadvantages.

Small commercial multirotor drones such as the DJI Inspire are readily available at low cost from offshore manufactures, and typically come fitted with gimballed cameras for aerial photography and surveillance. (Photo: Thomas Ehrhardt)

Multi-rotor vehicle: typically 4, 6 or 8 individual motors driving separate rotors. Takes off vertically and is most appropriate for local missions that require hover capability.

- (+) Mechanical simplicity and robustness. The only moving parts are the motors and rotors. Typically cheap and require minimal maintenance. The majority of consumer RPAS technology.
- (−) Aerodynamically inefficient and cannot carry as heavy loads or fly for as long as a single rotor or fixed wing configuration.

Single rotor vehicle: Typical helicopter configuration. Characterised by the presence of a swash plate mechanical system that allows the vehicle to be controlled through the main rotor.

- (+) The most aerodynamically efficient hover vehicle. All sky cranes are based on helicopter configuration and crewed helicopters use this configuration to maximise flight time and load capacity.
- (−) The swash plate mechanism is mechanically complex, expensive, and requires regular expert maintenance. Vehicles require a tail rotor or complex contra-rotating rotor system to control yaw. Helicopter rotors are large, extending well beyond the vehicle, and dangerous in confined landing zones.

Powered lift: A vehicle that flies in fixed wing configuration for missions but is capable of vertical take off and landing. Mostly configured with a separate quad or octa rotor system for take off and landing but also includes tail sitters and other convertible aerial vehicles.

- (+) Allows for small to medium aeroplane RPAS to be operated from landing pads rather than airfields.
- (−) The hover system for take off and landing is an additional drag and load penalty during mission operation. Tail sitters and tilt rotors do not overcome this limitation as the propulsion system for hover is very different from that for forward flight and design of the main propulsion system is compromised to achieve both goals.

Powered lift vehicles such as this Australian designed and manufactured Carbonix Ottano can be fitted with a variety of payloads and easily transported and operated in a remote location. (Photo: Andrew Tridgell)

Aeroplane: Fixed wing vehicle. Typically with wings and a tail assembly but also blended wing designs. Often with a rear mounted "pusher" motor to allow cameras and payloads to be mounted in the nose assembly.

- (+) This configuration is the most aerodynamically efficient, maximising payload and range. Larger vehicles fly fast and can deal with more extreme weather conditions.
- (−) Requires an airfield (or special equipment such as catapults, launch skids and nets) to take off and land.

Airship: A blimp or balloon.

- (+) Very low power consumption for hover flight. Capable of flying extremely high and providing pervasive ISR.
- (−) Slow and highly susceptible to gusts and wind. Requires a large volume balloon for reasonable payloads. Not appropriate for low level operation in fire conditions.

2.1.2 Operational Control and Autonomy

Present CASA regulations require all RPAS vehicles to be under control of a remote pilot, whether directly or in a supervisory role through a ground station ([Advisory Circular 101-01] Clause 3.1.12.2). Such a regulatory framework limits operations at the present time to one-pilot for one-vehicle in commercial applications. It is important to note that regulations allow for much more general operation for a class of "excluded RPA operations" where technology can be developed and trialled, and even operated over private property. Furthermore, CASA is open to updating regulations as technology is proven and safety can be assured. Many of the longer term applications of RPAS technology discussed in this roadmap require levels of autonomy of the vehicle that will only become reality with advances in technology around airspace management, data integration, and decision capability of the vehicle.

There are no well established levels of autonomy for RPAS documented in the literature. However Huang et al [Huang, 2006] provides a categorisation of autonomy that we have adapted into five levels that capture the key capabilities of RPAS for bushfire management applications.

Autonomy level	ALFUS level [Huang, 2006]	Description
1	1-2	**Remotely piloted**: Direct pilot control at all times.
2	3-4	**Autopilot**: Automatically follows routes between predefined waypoints. No onboard situational awareness.
3	5-6-7	**Operational level autonomy**: exteroceptive sensing of obstacles, weather, terrain, other vehicles. Autonomous manoeuvres and path reprogramming for obstacle avoidance within task parameters.
4	8-9	**Task level autonomy**: Independent prioritisation of actions to achieve tasks, collaborative reasoning for cooperative behaviours, localised decision capability to achieve a task.
5	10	**Mission level autonomy**: Capable of planning and executing complex missions from high level task descriptions. Replicates human level capability.

There are no commercial RPAS operating reliably above level 2 autonomy at the moment. Some RPA systems offer partial capability at level 3 autonomy, however, these systems are mostly at Technology Readiness Level (TRL) 6 (Prototype System Verified) [Heder, 2017] or below and there is remaining development work before the system is TRL9 (System Proven and Ready for Full Commercial Deployment).

Operational control and autonomy present in different manners depending on the application and nature of classes of RPAS.

Very small RPAS: Such vehicles are typically employed in local ISR "look over the hill" operations associated with remotely piloted level 1 autonomy. The pilot is typically directly controlling the vehicle and the sensor provides a direct local video feed. The pilot has direct situational awareness, passing information on to operational personnel verbally and no central data link is required. Such vehicles typically fly in Visual Line of Sight (VLOS) operation, that is, the pilot must be able to see the vehicle at all times.

Small RPAS: These vehicles require additional infrastructure but allow longer flight times and can be used for meso-scale situational awareness. Such vehicles will spend much of its operation flying at level 2 autonomy, on prespecified routes set by the pilot in charge who could be local at the fire ground command centre or centralised depending on the level of operation centre integration.

The payload sensor would be controlled separately from the vehicle in most cases and would typically be controlled by an information officer at the ground command centre. This may be the pilot or may be an independent person. Examples include; eye in the sky tethered RPAS above fire towers or command vehicles, post fire surveys during cleanup operations, and monitoring controlled burns. Such RPAS are also suited to deployment of incendiary devices to aid in back burning or setting controlled burns.

Medium RPAS: The role of medium scale RPAS in fire scenarios is large area surveillance and information gathering and provision of emergency communications. These vehicles would fly from regional control centres, fire stations, or other infrastructure. They would be centrally controlled through an operations centre with the pilot in charge running multiple vehicles to provide area wide ISR capability at scale and cost. Data would be centrally collected and distributed to area units and assets.

Large RPAS: The role of large RPAS in fire scenarios lies in transport of cargo to fire fronts to support existing operations and delivery of suppressant or retardant directly to an ignition or fire. Large RPAS would fly from regional control centres or airports and be centrally controlled by a pilot in charge in an operational control centre. Since the mission requirements involve direct involvement in the fire ground operations, and potentially integration with crewed aircraft activity, the airspace management system and obstacle avoidance systems are key capabilities of these systems.

In Beyond Visual Line Of Sight (BVLOS) flight, particularly for future scenarios where there are multiple vehicles supervised through a central operations centre, there must be a reliable radio communication link at all times between the RPA and the ground station. The link must be two way, carrying commands from the pilot and ground station up to the RPA, and telemetry and status back to the ground station. Additionally, payload data can be carried over this link for further processing by ground based systems.

Existing airborne sat-com solutions use gimbal stabilised, high gain antennas. Small panel antennas with electronic beam steering will allow integration into smaller vehicles, with higher bandwidths and lower costs. (Photo: NASA)

Redundant, high bandwidth data communication links are a fundamental part of RPAS operations. This is in contrast to small crewed aircraft operations that typically only have voice channel VHF available to communicate with the outside world. This point of difference naturally allows for RPAS integration into network centric operations with remotely located and centrally managed control centres. For operations of RPAS beyond visual range over remote territory not covered by terrestrial communications networks, satellite communications are typically employed. Existing solutions require a gimbal stabilised high gain antenna to link with geostationary satellites, placing constraints on the size and weight of the RPA. However, the emergence of Low Earth Orbit (LEO) satellite mega constellations [Al Homssi 2022] providing global broadband internet connectivity via small panel antennas, opens the way for smaller RPAS to use satellite based communications. LEO satellite mega constellations will be a key enabling technology for the emergence of long distance RPAS operations that can be controlled from centralised operations centres located anywhere in Australia as well as offshore. When these satellite communications networks are owned and operated from outside of Australia, emergency services relying on them will need to consider how to impose levels of service guarantees, similar to those currently placed upon service providers of domestic telecommunications infrastructure.

2.1.3 Payload

The role of an RPAS is to transport a payload to a point in space where it can operate effectively. ISR payloads are the most common on the smaller RPAS while the larger RPAS may drop incendiary devices for prescribed burns, transport equipment, or drop suppressant directly on ignitions or fires.

A typical ISR payload for fire monitoring includes a variety of sensors, such as RBG cameras for visual monitoring or other systems like thermal and hyperspectral sensors, that provide real-time video feeds or still frames to an operator. These sensors, regardless of their spectral range, are usually mounted on a pan-tilt gimbal system and can be servo-controlled independently from the vehicle's flight control, ensuring that the pilot-in-command and sensor operator can work autonomously from each other. The pilot is responsible for high-level mission operation involving routing of the vehicle to allow the payload to achieve its mission, while the detailed control of the payload is handled by an intelligence officer whose role it is to analyse the incoming data. Automation of these roles to allow the pilot-in-charge to operate multiple RPAS and all the intelligence operators to monitor and assign multiple payloads are key technologies to the future of RPAS operation in firefighting scenarios.

Cargo and equipment payloads are an important potential use of larger RPAS in the future. Getting equipment and material to ground based fire fighting operations, especially for RAFT and other remote firefighting activities, in a timely manner is difficult, dangerous, and costly. Larger RPAS offer significant potential efficiency gains and savings.

Direct firebombing payloads represent another critical potential application of RPAS technology for fire suppression. Existing crewed water bombing is highly efficient and effective and is undertaken as safely as possible given the constraints of an active fire field. However, it remains one of the more dangerous activities in aerial fire management and the potential to transition certain activities to RPAS offers potential safety gains. In addition, RPA can be scaled to the task required allowing for more smaller vehicles to deliver multiple payloads rather than relying on a single larger crewed vehicle. Although this is unlikely to replace existing water bombing activities, it may open new possibilities like targeted suppression of spot fires, breakouts when fires jump a firebreak or natural barrier like a road or a river.

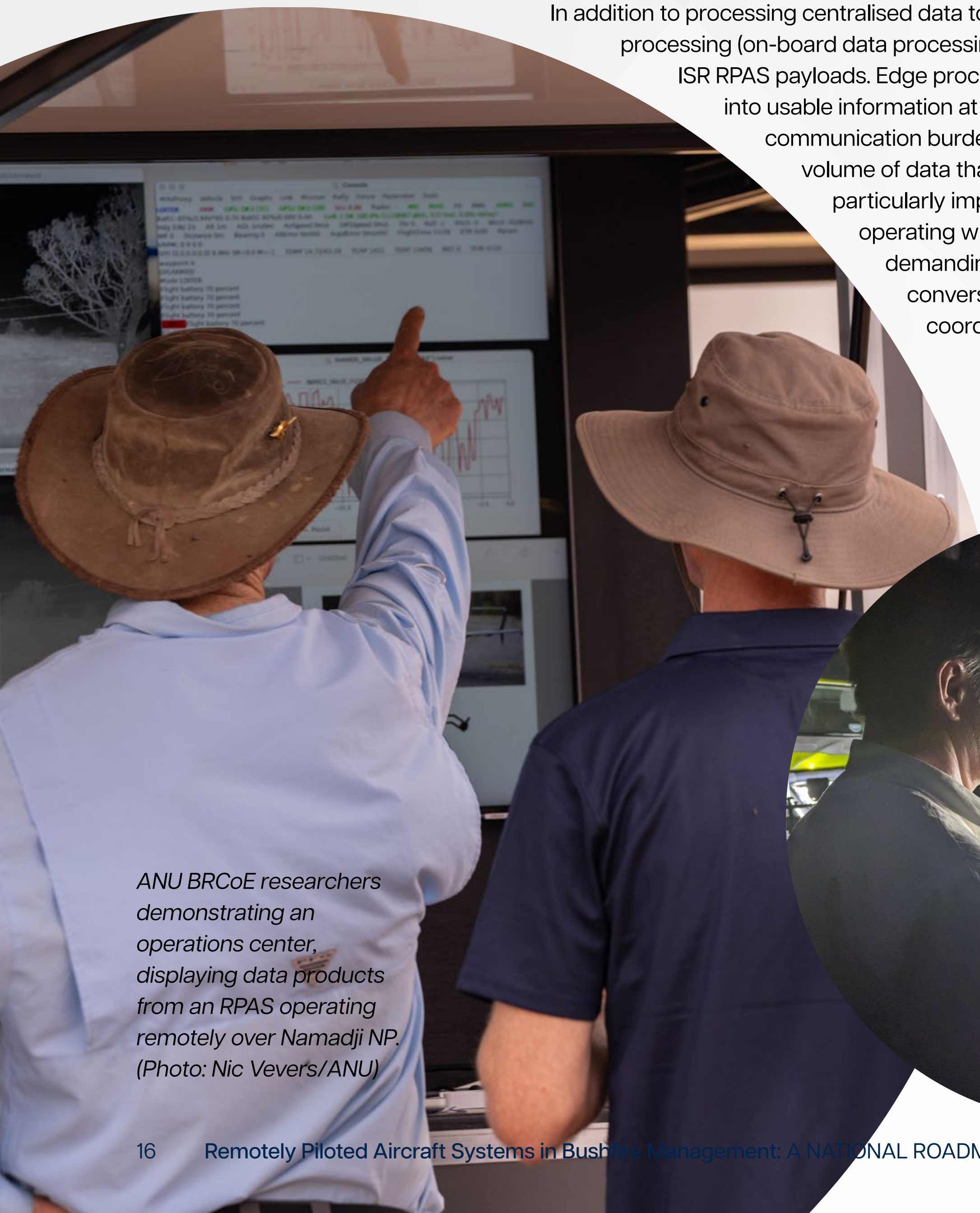
2.1.4 Data and Information Management

The importance of good data to underpin decision making in critical situations cannot be underestimated. With the right information, operational command can make well-informed decisions and maximise the effectiveness of firefighting activities. RPAS are introducing a significant paradigm shift in firefighting by providing extensive ISR data. However, the exponential increase in raw data that RPAS provide brings its own challenges, necessitating the development of dedicated technologies to convert this data into actionable information.

Providing raw data, such as the video feeds that many existing camera payload systems provide, directly to operational control centres is highly inefficient. Each visual feed, whether conventional vision, thermal data, LiDAR reconstruction, etc, requires a human to watch and focus on video. Video footage is intuitive and useful in some situations, but the exponential increase in the number and quality of such data will make them impossible to monitor effectively. Although some data products such as fire extent and fuel moisture content maps are already available, these products are usually produced off-line and from single mission data sets. There is a critical need to develop real-time analysis tools that consolidate multiple data feeds into usable information.

To enhance efficiency, data from different sensors must be centralised in cloud facilities. Once centralised, this raw data can be processed into various information products by multiple real-time analysis programs. These programs should distribute tailored information, such as fire behaviour forecasts or updated mission objectives, to units and personnel during firefighting and planning activities. This centralised system must integrate existing fire ground information, such as vehicle and unit locations, and metadata like planning and mission objectives.

In addition to processing centralised data to generate information, edge processing (on-board data processing) is a critical aspect of future ISR RPAS payloads. Edge processing helps convert raw data into usable information at the source, reducing both the communication burden for individual RPAS and the volume of data that needs to be stored. This is particularly important as the number of RPAS operating within a fire zone increases, demanding real-time data-to-information conversion to ensure effective and coordinated firefighting effort.



ANU BRCoE researchers demonstrating an operations center, displaying data products from an RPAS operating remotely over Namadji NP. (Photo: Nic Vevers/ANU)

2.2 Technology Horizons

In this section we speculate on a timeline for the development of key capabilities for RPAS systems for fire management applications. In proposing this timeline, we are assuming that there will be a continuing investment and willingness to engage with RPAS technology from the fire agencies as well as the expected growth of other RPAS and aerial mobility application domains. In addition, the more ambitious and longer term horizons will only follow if there is investment in research and development and a healthy environment for technological innovation in RPAS for fire management.

2.2.1 Horizon 1 (Short-Term): Enhancing Existing Capabilities [0-3 years]

- **Controlled burns ISR and incendiary operations:** Small to medium RPAS flown by service staff or contractors to support organised burns.
- **Data products**: Processed sensor data providing high level summaries such as detected ignitions, fire predictions, etc, rather than raw video.
- **Advanced sensing modalities**: New sensors for fuel characterization and fire detection and monitoring. Frame based hyperspectral cameras (rather than line scan), other new technologies.
- **Network communications**: Pervasive, reliable, and accessible communication networks for autonomous vehicles operating over remote high fire risk locations and over active fire ground.
- **Level 3 Operational autonomy**: collision avoidance in congested airspace, path replanning to avoid weather, terrain, etc.

2.2.2 Horizon 2 (Mid-Term): Advancing Autonomy and Data Integration [3-8 years]

- **Commercial long range ISR operations**: Growth of service companies to provide reliable ISR for pre- and post- fire surveys, ignition detection, and fire front mapping.
- **All weather operations**: Maturity of vehicle industry and development of standards and regulations to allow RPAS to operate in smoke, high wind, rain, storms, etc.
- **Level 4 Task autonomy**: Prioritisation of activity and actions to achieve tasks in collaboration with other RPAS, crewed aircraft, or other agents.
- **Centralised operations centres**: Highly efficient central operation centres capable of supervising multiple RPAS in the same active scenario.
- **Integrated airspace and joint operations**: Multiple RPAS and crewed aircraft operating in the same airspace to provide different capability and achieve collaborative outcomes.

2.2.3 Horizon 3 (Long-Term): Transforming Bushfire Management [8-15 years]

- **Interoperability and Standards**: The development of regulations, procedures and standards around operations, communications, and data for RPAS.
- **Data integration**: Integration and accessibility of multiple sources of data for the same fire scenario.
- **Distributed launch and maintenance infrastructure**: A network of landing pads and maintenance facilities to support a variety of long range RPAS activities across multiple application domains. Similar to the present network of airports, and possibly collocated in some cases, but targeted to RPAS technology.
- **Level 5 Mission autonomy**: Undertake complex missions from high level tasks descriptions. Comparable to capability of crewed aircraft.

2.3 Summary of key themes

The following discussion provides some key observations and analysis of RPAS technology in the context of bushfire applications.

Remotely Piloted Aircraft System Industry

A key foundation for successful application of RPAS technology in bushfire applications is the development of a RPAS industry, including an industrial ecosystem of technology providers, operators and operational support companies. Some of these companies may be international, however, some operators and operational support will need to be sovereign. Although the beginnings of such an ecosystem is in place, there is significant development required to get to the point where the Australian industrial base in RPAS technology supports the scaled delivery of RPAS for effective bushfire applications. A key roadblock is to close the technological and regulatory gap between the hobby industry and the aerospace industry. An exaggerated view of the industry would see that the hobby industry operates on small profit margins (per unit) and sells consumer technology with limited reliability, while the aerospace industry operates on very high profit margins (per unit) but delivers highly reliable systems. Bushfire RPAS applications lie in between these extremes, where systems must be reliable and operate in adverse weather conditions, however, where there is an acceptable loss rate for normal operations of systems. Finding the correct regulatory regime and setting cost expectations for service is a process that will take years to resolve.

Size

Many of the applications for bushfire operations will require medium to large RPAS. The primary driver is capability in the adverse weather conditions that are present in active fire situations. Small RPAS are simply unable to operate in high wind environments characteristic of active fire ground. Medium and large RPAS have higher cruise speed to deal with higher winds and better gust response to provide a more stable platform. There are limited commercial vehicles in this class available. While technology for smaller RPAS is available as Commercial Off The Shelf (COTS) components, equivalent technology for larger RPAS is not yet developed. There is a need to develop a technological ecosystem to provide the reliable and certified components that are needed for larger RPAS to be developed. This in turn will lead to improved operational capability in the large RPAS category where many of the longer term capabilities of RPAS in bushfires will be realised.

Sensors

The effectiveness of RPAS in bushfire management relies heavily on the data they collect. High-resolution conventional cameras, long-, medium-, and short- wave infrared, LiDAR systems, and multispectral sensors all provide valuable information for various applications. There are a host of specialised and powerful sensors developed for military applications for which the technology can be transferred to commercial use. Given an appropriate market these companies will begin to develop products that can substantially improve the quality of data available for bushfire analysis.

Communication networks

It is clear that while very small RPAS can function on existing direct communications technology, progressively larger RPAS will require more sophisticated air communication systems with redundant communication channels (such as satellite or mesh radio connectivity), centralised operation control centres where multiple RPAS can be monitored and routed, as well as ground crews and landing facilities with appropriate training.

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Airworthiness

Airworthiness is the ability of an aircraft to perform operations safely and reliably in all expected conditions. Airworthiness is an integral aspect of crewed aircraft design and construction with a history of best practice developed over a hundred years of flight engineering. Most of the smaller RPAS available are built on technology adapted from the recreational remote control aeroplane industry. This industry has little history of airworthiness regulation and operates on margins for which the overheads of airworthiness engineering is not practical. Medium and large RPAS used in bushfire applications will need to have a base level of airworthiness engineered into their systems, not necessarily at the same level as a crewed aircraft, but sufficient to ensure reasonably reliable operation in the conditions expected. It is the responsibility of CASA, to enforce safety and promote airworthiness of aircraft operations in Australia and operational crewed aircraft are subject to a rigorous certification process and are required to adhere to regular maintenance. There are the beginnings of the best practice being developed through CASA regulations and requirements for RPAS operation, however, this is an area that will require significant engineering and regulatory work over the next ten years as the industry develops.

Advanced Autonomy

Increasing the level of RPAS autonomy, particularly enabling safe and reliable beyond-visual-line-of-sight (BVLOS) operations. Basic capability like autonomous obstacle avoidance is the first step but advances in artificial intelligence, machine learning, and autonomous navigation systems will reduce the operational load on supervising pilots and enable them to manage multiple RPAS contributing the scale capability of RPAS operation. Research should focus on developing RPAS capable of independent flight planning, obstacle and traffic collision avoidance, and dynamic adaptation to changing environmental conditions.

Integrated Airspace Management

The safe and efficient integration of crewed and uncrewed aircraft in shared airspace is a fundamental requirement for unlocking the full potential of RPAS technology. Developing a robust regulatory framework, advanced air traffic management systems, and robust communication protocols to ensure safe and seamless operation of both crewed and uncrewed aircraft will be crucial for the future of aviation in bushfire management.

Operational Centres

The development and adoption of centralised operation centres that can provide supervisory control over multiple RPAS is a crucial step in achieving scale in RPAS technology. These facilities could be dedicated to a given application or company, but could also be a general facility that provides control for different companies and different RPAS. The centralisation of such a facility will significantly reduce the cost of operation at scale.

Distributed infrastructure

A second key requirement to achieving scale in RPAS technology is the development of a distributed network of infrastructure to support RPAS activities. As more large-scale commercial RPAS activities are undertaken in Australia, a network of RPAS landing pads with storage and maintenance facilities will need to be developed. Such facilities will play a role similar to airports for crewed vehicles but cater specifically to RPAS technology.

Cost of operation and scalability

There is already significant capability provided by operation of small RPAS by local fire fighting units in the field. Such systems provide ISR and potential incendiary capability in relatively benign conditions during controlled burns, post fire survey, vegetation surveys, etc. Employing larger RPAS for wide area ISR and operation during fire conditions is a much more costly endeavour. The cost of operation of a single RPAS can easily approach the cost of operation of a crewed vehicle for a similar task. However, the potential to scale RPAS technology is significant and is a crucial part of the future of RPAS operations in bushfire applications. The development of centralised operations centres that take control of multiple RPAS is a key technology that must be developed. Distribution of ground crews and support infrastructure, maintenance and storage facilities is another key requirement to achieving future scale. Once these roadblocks are addressed, multiple RPAS can be operated at a significantly lower cost point than crewed aviation systems, significantly increasing capability in ISR and active fire suppression provided for the same overall cost.

Data Management

A key requirement for exploiting the true potential of RPAS technology is the management and sharing of the large amounts of data that will become available as scaled systems are deployed. Such data needs to be accessible to everyone for post processing, whether it be through a centralised data hub, or through distributed data stores. The benefit of access to large and diverse data sets for an analysis algorithm is significant and will directly influence the quality and reliability of the data products that are produced. Ensuring open access of critical data sets to second tier data processing companies will require appropriate regulations and acquisition practices.

New Data Products

Many existing RPAS offer real-time visual feed from ISR payloads. Such a data feed has the advantage of immediacy and provides a powerful indication of the potential of RPAS for ISR. However, such data products will not scale and cannot be the foundation of a future network of multiple ISR RPAS. There is a need to start developing analysis programs, similar in nature to the recent work undertaken to develop fire detection from smoke for ground based camera systems, that yield data products that provide key information to key decisions when and where they need the information. There is a need for a significant development of technology to process and correlate large amounts of data to derive clear conclusions about ignition detection, fire front progress, vegetation mapping, etc.

Data Integration

The data collected by RPAS is only as valuable as its integration into existing fire management systems. Developing seamless data pipelines, allowing real-time data from RPAS to be incorporated into geospatial platforms, fire behaviour models, and incident command systems, is essential for informed decision-making and improved situational awareness.

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PART 3: Applications of RPAS in Bushfire Management

This section considers the current and potential diverse applications of RPAS technology across different aspects of bushfire management. The use cases have been grouped by applications with similar challenges and requirements: mapping fire grounds, active fire detection and monitoring, atmospheric monitoring, incendiary deployment, communications, transport and fire suppression.

RPAS technologies are presented from the perspective of what could realistically be possible in the longer term allowing for technical advances and changes to policy and regulation. Where existing RPAS solutions are already in use or could be deployed immediately, this is mentioned as well.

Aerial technology is a key part of existing fire management activities and existing crewed activities have been developed and optimised over many years. In some cases, RPAS technology overlaps existing crewed capability, while in other cases, it provides distinct new capabilities that crewed aircraft cannot provide. This part of the report does not try to argue one technology against the other, but simply outlines the capabilities of existing technology and the potential of emerging and future RPAS technologies.

3.1 Use Case Analysis

3.1.1 Mapping (fuel load, environment and assets, burnt area)

Fire and land managers use a range of mapping products collected before and after fires that inform decisions. These include pre-fire information such as comprehensive vegetation analysis including fuel type, fuel load, structure and moisture, as well as terrain mapping and infrastructure locations and status.

All of which enables sophisticated fire risk modelling that guides fire prevention or mitigation activities. Post-fire products include assessments of burnt area, fire severity, environmental impact and recovery as well as the effectiveness of prescribed burns.

Additionally, some data, including road and other infrastructure conditions and preliminary asset impact assessment, may be recorded during the response phase of fire management too. Active fire monitoring during fires has unique challenges that are discussed in a separate section below.

Existing solution: Spatial data is presently mapped using a combination of in person ground recording, along with imagery from crewed aircraft and satellites. For example, fuel characteristics may be mapped using a combination of ground measurements and statistical extrapolation across the landscape using aerial or satellite imagery. Domestic asset mapping may be informed by building registration records as well as aerial surveys or satellite data.

Opportunities for RPAS Technology: Fire severity[1], fuel structure[2], infrastructure damage[3] are among the various attributes of interest that have been mapped using RPAS, with the latter focusing on impacts to human-made structures within the landscapes. Most demonstrated use cases have been performed at a small scale using multirotor RPAS.

This scale of data collection is of immediate benefit to supplement existing data collection, particularly where site access or existing image acquisition prevent timely data collection. Larger RPAS with endurance approaching that of crewed aircraft that are capable of covering entire landscapes could decrease latency in detailed data acquisition, and could replace imagery collection from crewed aircraft or satellites, where those operations that involve significant costs, organisational or overheads, or are lower resolution.

1 Hillman et al., 2021a
2 Hillman et al., 2021b
3 Nath et al., 2022

Example RPAS Mission: Land management agencies may deploy a vertical take-off and landing (VTOL), fixed wing RPAS immediately after a fire has passed through a region. The vehicle will take off, climb and cruise overhead the fire affected area, streaming a range of data from on-board cameras back to the ground controller as well as to any data customers such as insurers and fire agencies via internet connectivity in real-time.

Data could include video footage for visual inspection, as well automated fire severity and fire perimeter mapping amongst other products. Data would be available immediately for post processing and same-day analysis that could inform critical decision making. Advanced data analysis exploiting the latest AI algorithms can provide deep insights and prediction to improve outcomes. The RPAS will require specific approvals to fly over 400ft AGL to provide greater field of view to onboard cameras, necessitating the mission be pre-approved for the given area.

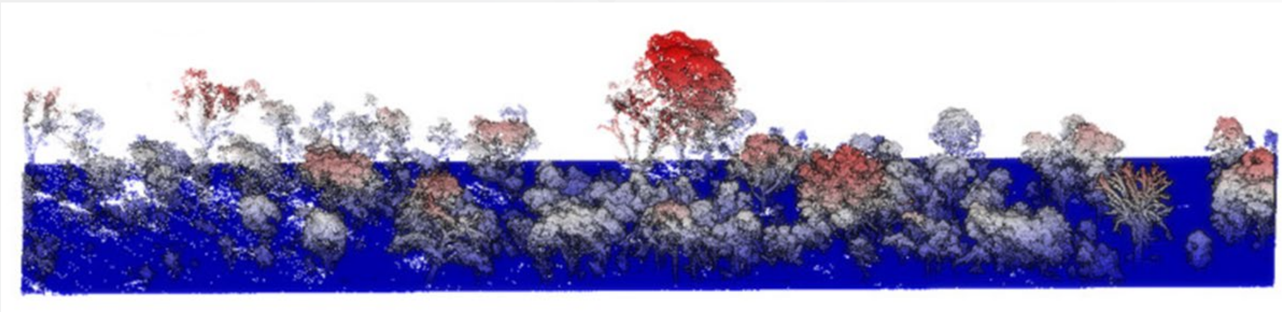
The RPAS will require additional technology and operational procedures onboard to assist with the deconfliction with other crewed aircraft and RPAS in the area. Should the RPAS have the requisite approvals for flight beyond visual range and above 400ft, the operator can cover large areas of fire affected land, providing real-time access to the data for small and large events as the cost of operation and the time to deployment will be very low compared with conventional aircraft.

Benefits and considerations: The anticipated reduced operating cost of medium RPAS compared with existing crewed ISR platforms, once operations are scaled, should allow greater access to high resolution mapping imagery. Additionally RPAS can undertake dull and dangerous missions, such as operating at low altitude for long periods to collect high resolution and detailed data, that would be high risk for crewed aircraft. The resulting data would provide additional information over and above that collected from high altitude aircraft and satellites – comparable to ground inspections but with more comprehensive coverage.

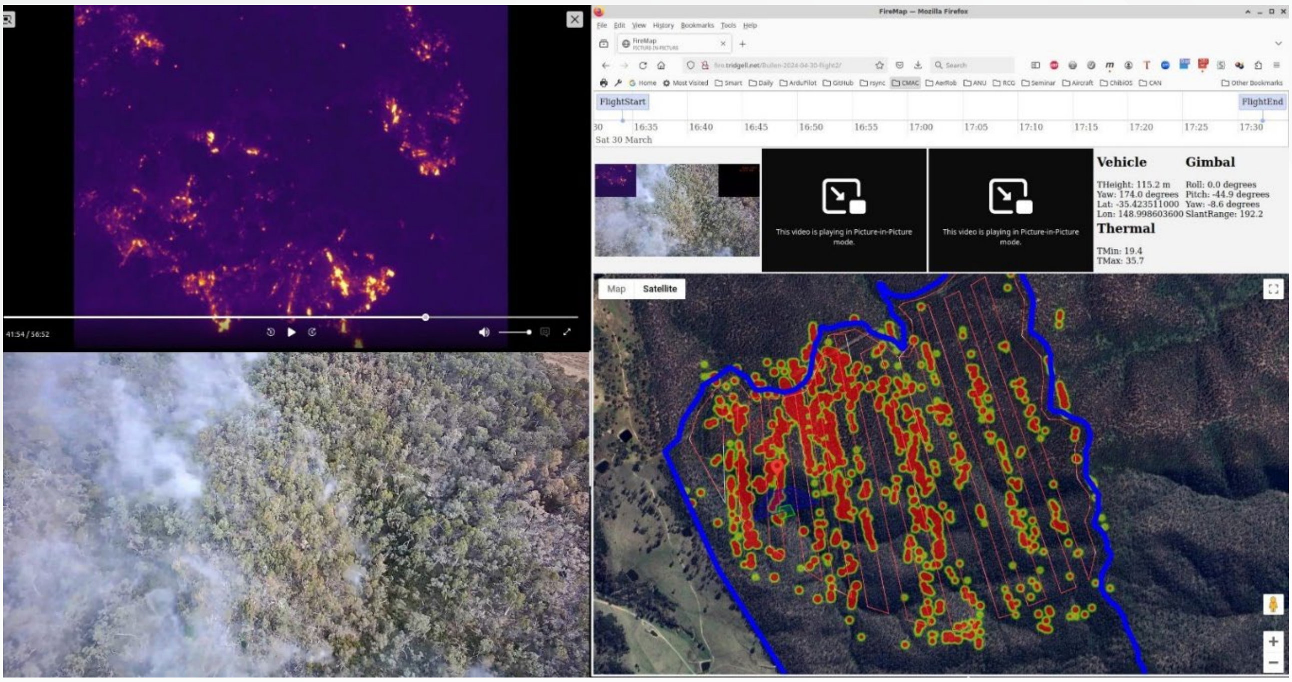
The absence of observer risk and subjectivity (compared to ground data collection or crewed aircraft) and flexibility in acquisition time (RPA can be deployed quickly and operated during various weather conditions and at any time day and night) may also enable more timely data acquisition, particularly during and immediately after fire events that are still ongoing.

Further, these mapping capabilities are typically applicable to other emergency response and management activities outside of bushfire management. The capacity for existing remote sensing platforms, such as satellite observation, to cover larger areas remains important for certain categories of data, however, RPAS can complement this data by rapidly collecting high resolution data across specific areas, and between satellite passes.

Point cloud captured with a LiDAR system, colored by height: red represents the highest points and blue represents the lowest points (Reproduce with permission from Shokirok et al. 2023)



Data products from processing optical and infrared RPAS imagery, collected during a hazard reduction burn. (ANU/BRCoE)



3.1.2 Support of Prescribed Burns

Fire managers ignite fires to perform prescribed burns (e.g. fuel reduction or ecological burns) and for back burning during active fires.

Existing solution: Prescribed burns and back burns are usually ignited on foot or from a vehicle, often using a drip torch. Crewed helicopters are also used for igniting prescribed burns, usually for larger prescribed burns in remote locations.

Prescribed burns and back burns are usually ignited on foot or from a vehicle using a drip torch, while larger burns in remote areas may use a crewed helicopter to deliver incendiaries. (Photo: Gary Hooker)

Benefits and considerations: RPAS incendiary delivery offers potential improvements in safety, efficiency and cost. A trial in the United States demonstrated a large increase in area burnt per day after implementing the use of RPAS incendiaries for prescribed burning (Lawrence et al. 2023). In Australia, the stakeholder consultation process indicated that incendiary trials have been undertaken in Queensland and Victoria although there is no public documentation of these trials at present.

There are risks associated with direct ignition from personnel, particularly during back burning operations and when flying crewed aircraft, that are eliminated when controlling the incendiary devices remotely. The vehicle can be moved around the fire ground rapidly, can access difficult terrain when compared to someone on foot or in a vehicle (which must remain on roads), and can hover closer to the ground compared to a crewed helicopter. The use of geofenced areas can also constrain the operation to avoid accidental ignition in areas not intended to be burnt.

Thus there are efficiency gains associated with the speed and accuracy of ignition deployment. The reduced cost of flying a small multirotor RPAS in comparison to a crewed helicopter is also likely to reduce the cost of use, and hence facilitate more frequent use of these devices.

There are currently limitations in range and operating time associated with small multirotor platforms that crewed helicopters do not suffer from and crewed vehicles may remain more appropriate for larger burns. RPAS incendiary vehicles are expected to scale in size to reduce the capability gap between crewed assets and in the interim should be seen as a capability multiplier providing aerial incendiary capability to small to medium burns that presently would not warrant the deployment of a crewed vehicle.

Opportunities for RPAS Technology: Small to medium multirotor RPAS with purpose-built incendiary payloads have successfully been trialled for prescribed burn operations in the United States (Lawrence et al. 2023) and Australia. Like existing crewed helicopter incendiary devices, the RPAS solution drops incendiary balls that cause an ignition upon contact with the ground, starting a fire in the desired locations.

While current research and demonstrations have focused on prescribed burning, these same platforms could be used to conduct back burning operations during active fires. Multirotor platforms are likely to be the most suitable platform for this purpose as they can easily hover over a target location for accurate payload delivery.

Incendiary delivery is typically only required in a limited spatial extent and can be achieved using a multirotor platform that is deployed and operated from the local unit.

Example RPAS Mission: A medium (25-150kg) multirotor RPAS with a payload of incendiary balls may be operated by a land management agency for the purpose of conducting fuel reduction burns. The RPAS could be operated by two pilots, situated at different vantage points to maintain visual line of sight with the RPAS during low visibility conditions caused by smoke or dense foliage.

The RPAS will enable precision drops of incendiary devices in difficult to access terrain whilst simultaneously providing overhead video footage accessible to the remote pilots and ground crews via an internet based logon. This RPAS could be owned and operated by the land management agency or contracted in by a third party and, as the market scales, is likely to be cheaper and more efficient than existing solutions.

Saidynamics' Bremer 80 multirotor RPAS delivers incendiary devices from an onboard dispenser unit during a controlled burn in Gibb River, WA. (Photo: Saidynamics)

3.1.3 Atmospheric monitoring

Monitoring of weather conditions and air quality form an important part of bushfire management as they inform prescribed burn operations, strategic firefighting and containment decisions and identify periods of poor air quality.

Existing solution: Meteorological agencies routinely provide fire managers with point, gridded and regional weather forecasts and data relevant to various fire management operations. Model based data interpolation can perform poorly at reporting conditions in complex terrain or where active fires interact with the atmosphere.

Portable weather stations are often used for this purpose, but cannot be easily moved as required and only report surface level weather conditions. Air quality monitors are also used for monitoring air quality around populated areas, but are also limited by their fixed terrestrial position.

Meteorological instruments and air quality sensors are fitted to crewed aircraft for more detailed data collection [AMDAR 2024], however, due to logistical and cost constraints data collected is sparse both temporally and spatially. The Aerosonde [Aerosonde, 2024] aircraft was designed (in the 1990s) specifically for weather data collection over the Indian ocean and is an example of such a vehicle.

Benefits and considerations: RPAS equipped with atmospheric monitoring instruments create a new capability for fire managers to monitor weather conditions and air quality in specific locations and provide more locally representative and up to date information. These products do not replace existing solutions that produce more accurate and reproducible data, but add capacity to resolve spatial uncertainty under specific circumstances. This data collection capacity may also be beneficial across a range of other situations such as monitoring other emergency situations or sources of poor air quality.

Opportunities for RPAS Technology: Meteorological instruments and air quality sensors could be fitted to RPAS, thus enabling rapidly deployable monitoring of atmospheric conditions where needed. Existing remote stations could be fitted with eye-in-the-sky autonomous quadrotors that ascend tens to hundreds of metres high to sample the weather above the station providing much richer data.

Several studies have demonstrated atmospheric monitoring on small to medium multirotor RPAS. However, various platforms (both hovering and moving) could be used depending on the required data. For example, larger and more robust vehicles may be required for data collection under windier conditions or at higher altitudes.

Example RPAS Mission: A medium powered lift vehicle (capable of VTOL but flying in fixed wing configuration) could be equipped with instrumentation to measure atmospheric conditions and in periods leading up to high fire danger and on days of catastrophic fire danger. The atmospheric conditions that most influence the propagation of fire are temperature, humidity and wind. Detailed real time information will significantly enhance planning in fire management operations.

3.1.4 Fire detection

Bushfire managers require rapid notification and confirmation of new bushfires to enable initial attack while fires are small and easier to suppress.

Existing solution: Fire agencies are typically notified of new bushfires by members of the public (000 calls etc), fire tower reports and ground patrols. Crewed aircraft are used during high risk periods and provide ignition detection and in remote regions. For example the Department of Biodiversity, Conservation and Attractions (DBCA) in Western Australia operates a fleet of 10 spotter planes [ABC news, 2024]. The low spatial or temporal resolution (or both) of satellites impedes detection of small (<1ha), low intensity fires, but can play an important role, particularly in remote areas where aerial or terrestrial detection sources are sparse. Many fire agencies have reported ad-hoc use of small multirotor platforms for detection and monitoring purposes without automated detection or geolocation capabilities.

Benefits and considerations: RPAS presents several opportunities in fire detection. Firstly, the scalability of the platform will enable missions that could compliment existing solutions (e.g. networks of tethered multirotors monitoring the surrounding landscape without occlusion). The range of RPAS vehicle types and unique technical and safety constraints mean that there are a range of potential novel RPAS detection mission strategies that could become available to fire managers. These new capabilities can add to existing capabilities and some may be more accessible to agencies with smaller budgets.

The absence of risk to air crew is a key capability driver for RPAS systems. This enables missions such as flying near to dry lightning thunderstorms, during the early morning before sunrise, and in the presence of heavy smoke as was the case in the 2020 fires.

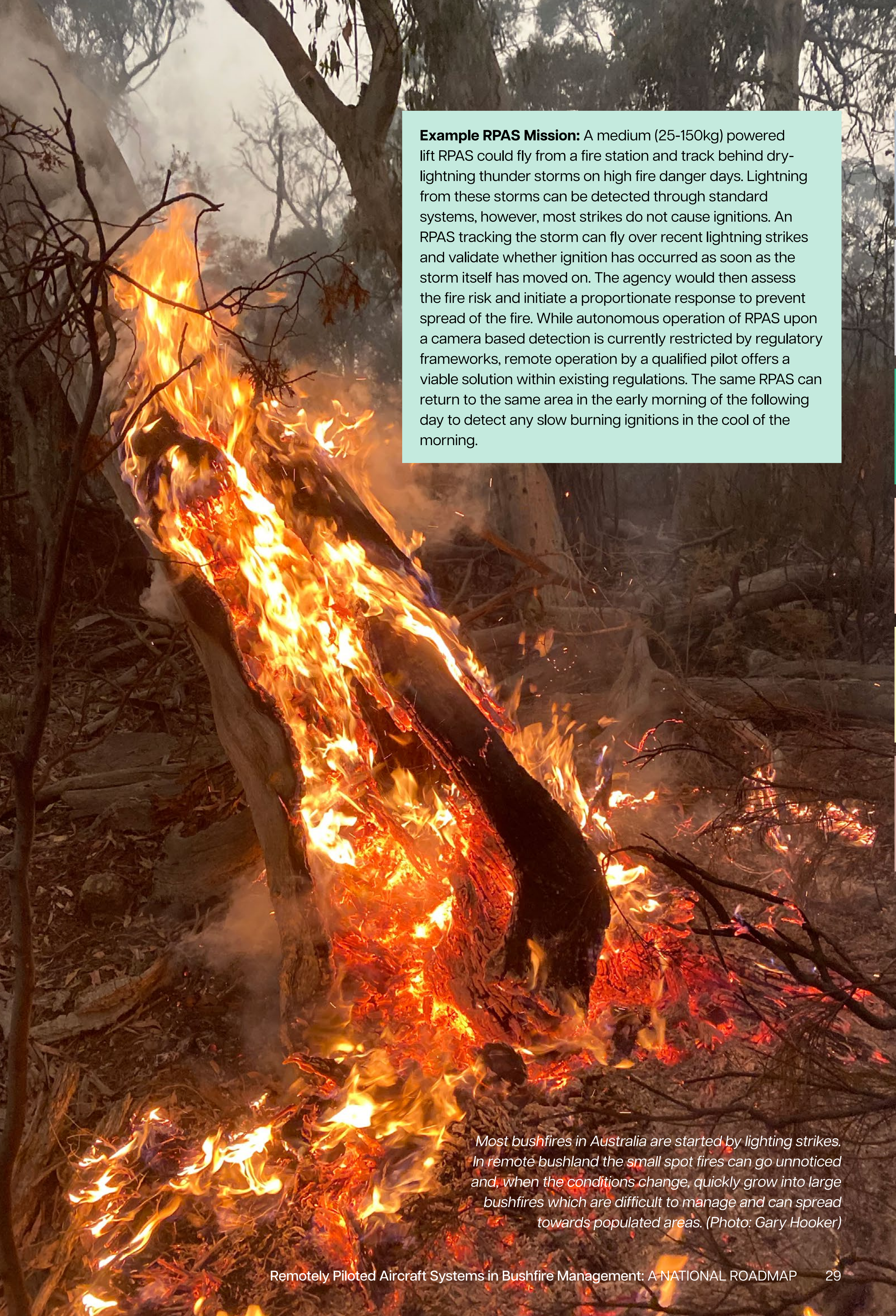
Opportunities for RPAS Technology: RPAS detection and monitoring missions could include surveillance of high risk areas during periods of elevated fire risk and confirmation of suspected ignitions (e.g. confirming that a smoke sighting is from a previously undetected fire).

The ability of RPAS to obtain direct sightings of the fire also facilitate accurate geolocation of new fires. New bushfires can be detected on RPAS platforms with a combination of payloads including infrared or thermal cameras (heat detection), RGB/visual cameras (detection of smoke or flames) and gas sensors (detection of smoke and other gases). Fire location information can only be accurately obtained using imagery of the fire itself.

A range of platforms and mission types could be used in the future, including but not limited to:

- Tethered very small or small multirotor RPAS could augment fire towers by hovering above the fire tower at a suitable altitude to monitor the surrounding landscape without occlusion and improve field of view.
- Small to medium fixed wing or multirotor RPAS could be deployed in strategic locations for rapid, autonomous searching or monitoring of an area individually or as part of a swarm.
- Long endurance fixed wing RPAS can search or monitor for fires across larger area (approximately 1000-10,000 hectares) individually or as part of a swarm.
- High altitude long endurance fixed wing RPAS could search or monitor entire jurisdictions (1,000,000 hectares).
- High altitude blimps can continuously monitor a fixed region (1000-1,000,000 hectares) for an extended period of time, similarly to a geostationary satellite but with higher resolution.

Presently, the relatively small number of aircraft (crewed and remotely piloted) performing detecting missions does not incentivise investment in automated detection algorithms. The potential to operate many more RPAS simultaneously may justify investment in automated detection algorithms to reduce the reliance on personnel and increase the efficiency of monitoring operations.



Example RPAS Mission: A medium (25-150kg) powered lift RPAS could fly from a fire station and track behind dry-lightning thunder storms on high fire danger days. Lightning from these storms can be detected through standard systems, however, most strikes do not cause ignitions. An RPAS tracking the storm can fly over recent lightning strikes and validate whether ignition has occurred as soon as the storm itself has moved on. The agency would then assess the fire risk and initiate a proportionate response to prevent spread of the fire. While autonomous operation of RPAS upon a camera based detection is currently restricted by regulatory frameworks, remote operation by a qualified pilot offers a viable solution within existing regulations. The same RPAS can return to the same area in the early morning of the following day to detect any slow burning ignitions in the cool of the morning.

Most bushfires in Australia are started by lighting strikes. In remote bushland the small spot fires can go unnoticed and, when the conditions change, quickly grow into large bushfires which are difficult to manage and can spread towards populated areas. (Photo: Gary Hooker)

3.1.5 Active fire Intelligence, Surveillance and Reconnaissance (ISR)

Monitoring of active fires including mapping of the area burnt and active fire extent, as well as fire behaviour monitoring help to inform fire fighting and containment activities as well as fire spread prediction and emergency warnings.

Existing solution: Ongoing mapping and observation of active fires is performed through a combination of ground observation, satellite imagery and piloted aircraft surveillance. Crewed aircraft, both fixed wing and helicopters are used for situational awareness.

Piloted aircraft equipped with infrared cameras for mapping entire fire grounds produce the most complete and accurate sources of fire mapping and intensity data (often known as linescan data) for large fires. Satellite data is also increasingly used for mapping known active fires and monitoring fire intensity, but the spatial resolution or the observation frequency of these data usually limit their utility.

Fire agencies are currently using small to medium multirotor RPAS for situational awareness, however, these are operated locally in direct remote mode and the data is purely visual and not incorporated into data collection systems.

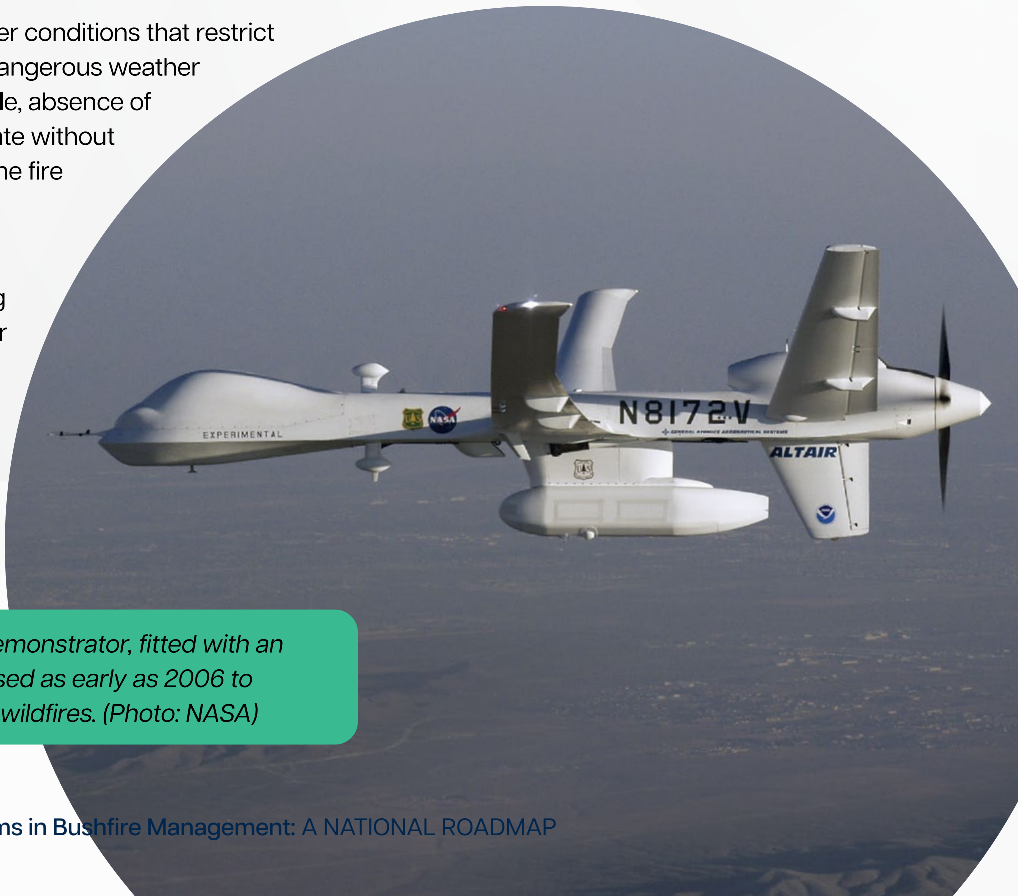
Benefits and considerations: High resolution fire intensity mapping is essential for up to date fire spread predictions that are used for emergency warnings and strategic fire fighting decisions. RPAS can operate day and night, and their use can scale, providing intelligence whilst other aircraft are grounded or unavailable. The reduced flight risk and potentially lower up front and operating cost associated with flying RPAS compared to crewed aircraft may facilitate more routine aerial monitoring of active fires (rather than just larger fires).

RPAS may be able to collect data under conditions that restrict crewed aircraft flights (thick smoke, dangerous weather and night time conditions). For example, absence of risk to air crew and capacity to navigate without visibility may enable flights ahead of the fire front to identify spot fires.

Scalability of the RPAS platform may also make accessing aerial monitoring more affordable, thus enabling greater usage.

Opportunities for RPAS Technology: Visual imagery could enable situational awareness flights similar to those currently performed by crewed aircraft. Infrared imagery would enable accurate mapping and monitoring of fire behaviour. Fitting additional sensors to map fuel, terrain and weather may also facilitate more accurate fire behaviour predictions.

A key opportunity with increased scale of operations is integration of data generated by RPAS. If this data is incorporated into analysis systems and fire modelling then rather than eye-in-the-sky visual feed, fire units and commanders could access maps of fire progress, predictions of future fire progress, hot spot identification, information about vehicle access and status of roads and infrastructure, data on which assets were where, and their progress on fire mitigation activities on tablets and other devices in real time when and where they need to make decisions.



The Nasa Altair RPAS technology demonstrator, fitted with an infrared imaging sensor pod, was used as early as 2006 to provide ISR during large Californian wildfires. (Photo: NASA)

Example RPAS Mission: A medium to large (25kg-150kg+) fixed wing RPAS will take off from a closed road or airstrip nearby to an active fire. The RPAS will require technology, such as ADS-B and detect and avoid, to transit through either controlled or Class G (un-controlled) airspace in order to reach the active fire.

Once overhead the fire, the RPAS will loiter at best endurance speed for 12+hours, remaining above the firefighting aircraft in the stack for deconfliction. Equipped with an array of visual, infrared and hyperspectral camera sensors capable of seeing through the smoke, the RPAS will provide the incident commander strategic intelligence on the behaviour of the fire as well as real-time awareness of assets in the area.

This operating model will require specific flight authorisation for operating beyond visual line of sight of the remote pilot as well as flight above 400ft AGL. The complexities of operating a large fixed wing RPAS are likely to necessitate this mission be provided by a third party rather than within the fire agencies.

Australian Federal Police, with the assistance of the ACT Rural Fire Service, flying a multirotor RPAS with an EO/IR camera payload in search of spot fires during the 2020 Black Summer. The smoke conditions and poor visibility grounded crewed aircraft and this was the first time drones had been used in the ACT to support operational fire-fighting. (Photos: Gary Hooker and Garry Mayo)

3.1.6 Communications

Maintaining communication is essential for safe and effective bushfire management operations and public safety, particularly in remote areas with limited communication infrastructure. Certain parts of the landscape have limited or no communication infrastructure, or may be subject to communication outages due to infrastructure damage during bushfires. Maintaining reliable communications is likely to become more important with increasing use of aviation technology and as larger fires potentially cause more frequent infrastructure damage.

Existing solution: Infrastructure such as the internet, mobile and fixed line telephony, and radio is used for the majority of communications. Emergency radio towers in particular are important for maintaining communications in remote areas during fire activity. The emergence of satellite based communications may also facilitate more robust communications.

Benefits and considerations: Development of RPAS communication infrastructure can provide reliable communication during fire management procedures and ensure secure communications with vulnerable fire fighting crew and members of the public. While emerging satellite based communications also address this problem, RPAS may be a solution when satellite communications are unavailable or in topographically complex regions that are not well-served by other platforms.

Capacity to host short range communication platforms may become important for managing fire fighting personnel and assets including RPAS and other aviation technology. This technology is not uniquely relevant to fire management and could be used across a range of emergency situations.

Opportunities for RPAS Technology: RPAS vehicles have the capacity to act as temporary communications platforms for both ongoing fire management operations in remote areas, and when infrastructure is damaged by fire. Investment in this technology was specifically recommended by the 2020 New South Wales Bushfire Inquiry (Owens and O'Kane, 2020).

Smaller platforms such as multirotor RPAS may be sufficient for providing communication support during small operations such as prescribed burns. If these vehicles are tethered then they can be powered through the tether and have effectively unlimited flight time. Long endurance hover platforms such as dirigibles may be a better solution for more prolonged situations such as major communication outages during emergency events.

The dependence of modern society on mobile communications and the growing use of apps on mobile phones and electronic data pads for fire management logistics including personnel and asset tracking as well as aviation management makes it critical to ensure mobile coverage during an emergency situation, even in the event that fixed communication towers are damaged or destroyed.

Example RPAS Mission: Combined with the active fire intelligence example, a medium to large, fixed wing RPAS with significant endurance (>12 hours) could be equipped with radios and a 4G repeater. Such a vehicle will be equipped with technology, such as ADS-B and detect and avoid, to transit through either controlled or G-class (un-controlled) airspace.

Once in place, the RPAS will loiter at best endurance speed for 12+hours, remaining above the active vehicles providing connectivity to ground and air assets which suffer terrain blanking or are outside of coverage.

This mission is similar in nature to the ISR mission outlined in 3.1.5 and the same vehicle could be used for both missions as long as it was large enough to manage the payload.

3.1.7 Transport

Access to fire fighting and emergency management resources can affect fire fighting activities due to delays in delivery. Furthermore, fire fighting personnel and communities that are isolated by fires may be dependent on delivery of essential resources by air or by boat.

Existing solution: Resources are delivered by a range of vehicles depending on the size, quantity and urgency of delivery. During bushfire emergencies delivery of urgent or essential goods and evacuation are often performed by crewed aircraft or boat as land transport may be unsafe or impossible. In particular, Remote Area Fire Teams (RAFT) rely heavily on support by air, including logistics support and transport.

Benefits and considerations: RPAS offers an efficient means of transport of resources to fire grounds and isolated communities. This technology is also beneficial for other emergency management situations, such as resource delivery to communities isolated by flooding. This may be a safer and more cost effective solution than crewed aircraft in emergency situations. The scalability of the platform can also enable more widespread uptake than is currently possible with crewed aircraft. Crewed aircraft are likely to remain dominant in the delivery of larger items while RPAS solutions begin with smaller deliveries such as medicines and communications devices and increase capacity as suitable platforms become available.

Opportunities for RPAS Technology: The development of the RPAS based food delivery industry has demonstrated that smaller goods can be efficiently delivered using small RPAS platforms, such as multirotors, over shorter distances. This could enable the safe and fast delivery of food, water, first aid and fire fighting resources to fire fighters and the public. The size or quantity of delivered goods could potentially increase with RPAS size.

Example RPAS Mission: A large RPAS rotor vehicle could be deployed to support Remote Area Firefighting Teams (RAFT). Such a vehicle would fly from a local depot or landing pad with a cargo of equipment or packaged water that could be winched down through tree cover and delivered to where it is required. Equipment could be delivered before the RAFT arrives so that the materials are available immediately once they arrive on the scene. Moreover, cargo could be delivered only when required, saving significant time and energy of the crew moving heavy equipment and water around by hand. The vehicle would need to be centrally coordinated by a pilot in charge with a local support crew to load and refuel.

3.1.8 Fire suppression

A combination of water and fire retardant chemicals can be used to directly suppress active fires and ignitions or dampen fuels ahead of the fire front.

Existing solution: Ground based solutions include backpacks carried by fire fighting personnel and vehicle mounted systems, used where personnel can access a fire relatively safely. Hand tools and bulldozers are used for clearing fuel ahead of fire fronts. Crewed helicopters and fixed wing aircraft are used for aerial water application, typically referred to as water bombing. Water bombing strategies can broadly be broken down to direct attack (bombing the flaming area of the fire ground), or indirect attack (bombing ahead of the fire or around ground personnel and assets to temporarily wet fuels). The quantity of water (which is often mixed with retardant) delivered may vary from 400L to over 10,000L depending on the aircraft. Choice of aircraft is influenced by the quantity of suppressant required, distance to water sources (fixed wing craft are advantageous where the fire is further from a water source), aircraft availability, flight restrictions and cost.

Benefits and considerations: Aerial water bombing is an established tool in bushfire management and plays an important role in preventing fire growth and allowing ground crews to access and extinguish ignitions. The use of RPAS for aerial delivery of suppressant eliminates the risk to fire fighting aircrew that are presently required to deliver the suppressant.

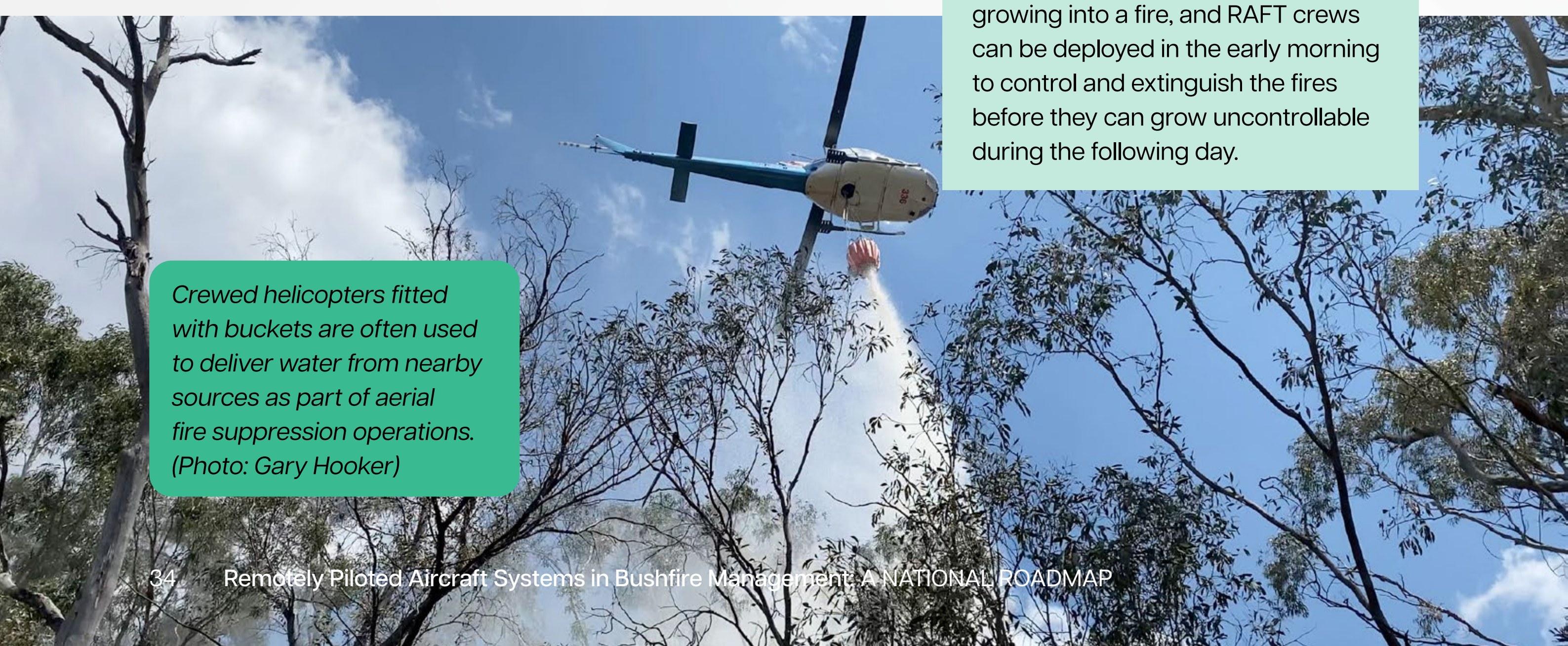
Fire agencies in the United States are evaluating the use of remotely piloted helicopters [Avionics International, 2023] for night time water bombing activities, which is considered higher risk for crewed aircraft operation. Development of this technology may also facilitate new fire fighting strategies, such as direct delivery of suppressants to establishing fires or spot fires.

There remain significant practical challenges to designing an effective and efficient RPAS suppression system which is likely to limit this application for some time. The potential for operation in dangerous and difficult conditions such as at night time, with low level flight in rugged terrain, and with high winds and possibly smoke, will be the entry point for technology of this nature.

Opportunities for RPAS Technology: RPAS have the potential to perform aerial fire suppression activities similarly to crewed aircraft. Two suppressants have been proposed for RPAS based fire suppression: water (likely mixed with retardant) and fire suppressing 'bombs' that disperse fire retardant upon impact with the ground. Further, there are two primary models of delivery: swarms of smaller RPAS delivering suppressants in coordination, and crewed aircraft retrofitted for remote operations to deliver suppressant in higher risk environments.

Example RPAS Mission: Following an evening lightning storm, ignitions caused by dry lightning strikes are identified in rugged bushland. As night falls, a converted agricultural aircraft is flown remotely, and in future autonomously, from a nearby airfield undertaking regular water bombing runs by GNSS control of the area around the ignitions throughout the night.

Such a vehicle would require autonomous DAA (detect and avoid) and ADS-B, and would be controlled through a centralised operations centre, with a local ground crew providing refuel and support. By water bombing throughout the night, the ignitions will be prevented from growing into a fire, and RAFT crews can be deployed in the early morning to control and extinguish the fires before they can grow uncontrollable during the following day.



Crewed helicopters fitted with buckets are often used to deliver water from nearby sources as part of aerial fire suppression operations. (Photo: Gary Hooker)

3.2 Summary of key themes

This section summarises key aspects related to the integration of RPAS in fire management, grouped by overarching themes, that have been discussed earlier offering a consolidated view of the potential opportunities, challenges, and implications of incorporating RPAS into fire management strategies independently of the specific application.

3.2.1 Safety

Amongst the benefits of RPAS is that they provide the opportunity to utilise aviation assets in higher risk environments such as poor visibility, where the use of crewed aviation would exceed a risk threshold. RPAS use will also enhance the situational awareness of ground crews leading to improved safety outcomes.

On the negative, RPAS introduce additional complexity to the airspace over an active fireground. Safe integration of RPA Systems with crewed aviation is highly challenging and a reliable technology to address this challenge does not exist at the moment. Introducing RPAS into crewed airspace at the present time would increase risk to existing activities and has been identified as one of the key challenges facing RPAS in fire management. There is also the risk to personnel on the ground from RPAS failure during missions over operational areas. The mitigation of ground and air risks for RPAS operations is critical for increased uptake and is anticipated to be a focus of the industry for Horizon 1.

3.2.2 Size

Because RPAS vehicle size and capabilities can vary greatly, an appropriate vehicle can be chosen for a specific application and budget. By contrast, crewed vehicles must accommodate the crew, hence the minimum size and safety requirements creates an operational and entry cost barrier. In crewed vehicles, payload capacity must be sacrificed to crew and cabin, and the vehicle size may exceed what is needed for mission design and payload. Hence, mature RPAS technology should make certain aerial fire management capabilities more affordable and accessible to fire managers.

For example, fire managers can monitor the extent and behaviour of multiple prescribed burns with small to medium multirotors, a capability that would be reserved only for large prescribed burns with a crewed aircraft. The scalability of RPAS can supplement many existing aerial fire management capabilities. The advantages of performing operations with RPAS diminish as vehicle size increases and overlaps with the domain of crewed aircraft.

3.2.3 New Capabilities

Technical, safety and financial constraints limit the application of both existing fire management capabilities and novel RPAS solutions. The constraints on RPAS, as distinct from other technologies, enable the potential for new capabilities and mission designs that are not currently feasible or even possible. Similarly, the constraints on RPAS capabilities, particularly in the near term, are significant and will limit where they can augment existing capabilities. Consequently, RPAS should be viewed as a new capability in bushfire management, rather than as an alternative to existing aerial solutions.

3.2.4 Wider application

Significant investment into research, development and acquisition is required to fulfil the potential of RPAS fire management capabilities. Budgetary constraints limit the ability of fire agencies to address this challenge effectively by themselves. Fortunately, this challenge is not exclusively in the domain of fire management. Many of the advances in RPAS capabilities will be driven by the wider RPAS industry, independently of fire and emergency management. Further, many of the capabilities described here are applicable or similar to other fields or emergency and land management, which can help to facilitate advances towards an all hazards approach. There remain several capabilities that are unique to fire management though, and will require investment for this sole purpose.

3.2.5 Cost and Scalability

As many of the RPAS fire management solutions described here are not currently developed, any cost benefit is highly speculative. The cost of operating a technically proficient RPAS system that meets regulatory requirements may be greater than may be expected due to the requirements on infrastructure, support personnel, etc. Indeed, the cost of operating a small number of RPAS is expected to be as expensive as crewed aviation. However, the infrastructure, support personnel, operations centres, etc, will scale efficiently. As long as data analytics are developed in concert with the RPAS technology in order to remove the requirement to have personnel directly analysing video or other data in real time, then RPAS technology for fire management has high potential of cost savings at scale.

3.2.6 Early adoption

The key opportunities for early adoption of RPAS technology revolve around scenarios where RPAS technology can allow existing activities to be scaled up, such as expanding surveillance capabilities, increasing the efficiency of ignition for prescribed and back burns, or providing new capabilities, such as tethered RPAS with cameras improving fire tower field of view.

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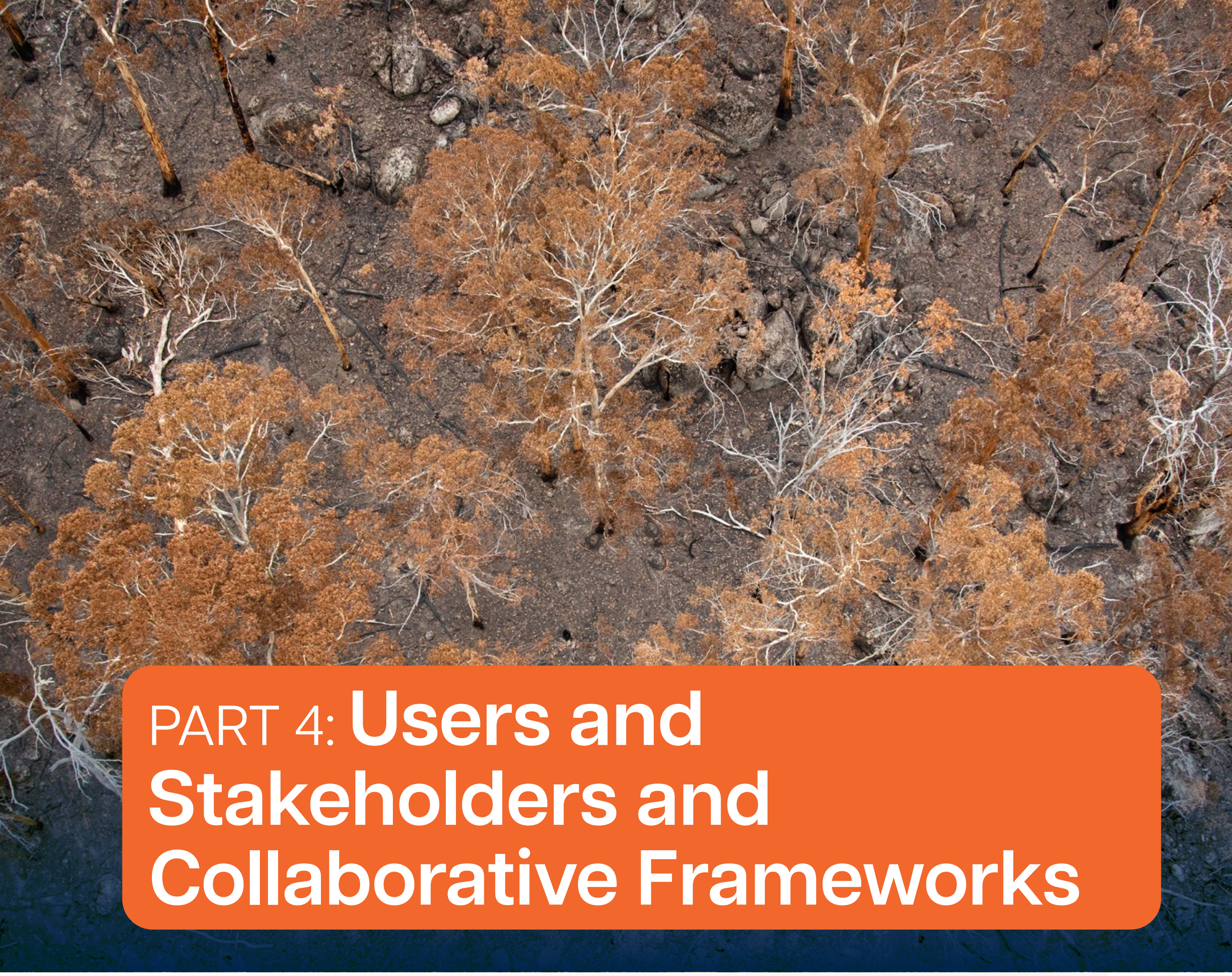

PART 4: Users and Stakeholders and Collaborative Frameworks

The successful integration of RPAS into Australian bushfire management requires a collaborative effort involving a diverse network of stakeholders. This section identifies key stakeholder groups, outlines their roles and responsibilities and highlights their contribution to the industry.

4.1 Outline of stakeholders

The stakeholder engagement phase occurred over a period of 5 months and involved interviews with over 40 organisation representatives and included a survey with approximately 65 respondents from the industry. Annex A tabulates each of the stakeholder agencies engaged and Annex B provides insights into the survey responses.

4.1.1 Land Managers

Land managers are government or private organisations which hold responsibility for large volumes of land. This includes the management of bushfire on those lands, however the approaches taken can vary significantly. Commercial plantations such as HQ plantations in Queensland or HVP Plantations in Victoria have a financial incentive to invest in preventative measures and rapidly respond to unplanned fires. In 2023 the Department of Agriculture, Fisheries and Forestry reported the total area of plantations in Australia to exceed 1.7 billion hectares, an area 7 times larger than the ACT. State land managers such as NSW National Parks and Wildlife Service and Tasmania Parks and Wildlife Service have the flexibility of a risk based approach where resources can be used sparingly to mitigate fire risk. Ultimately land managers are all responsible for management of fire on their land, however there is usually collaboration between the state fire services. The crossover in responsibility varies across the states, but is typically linked to risk of life and property. Land managers typically have dedicated firefighting capabilities therefore are considered to be one of the end users for emerging aviation technology.

4.1.2 First Responders

State firefighting agencies, including the Rural Fire Services (RFS), are primarily responsible for coordination and emergency response to bushfires and in some states, urban fires. State firefighting agencies hold additional responsibilities in the pre-fire and post-fire duties. First Responders are considered one of the end users of emerging aviation technology. The principle state fire agencies are: ACT Fire & Rescue and ACT RFS, Queensland Fire Department and QLD RFS, Fire Rescue Victoria and CFA (Country Fire Authority) in Victoria, the Metropolitan Fire Service and Country Fire Service in South Australia, Department of Fire and Emergency Services (DFES) in Western Australia, NT Fire and Rescue Service and Bushfire NT in Northern Territories, Tasmania Fire Service, and NSW Fire and Rescue and NSW RFS. Many states have additional agencies associated with specific infrastructure such as airports etc.

4.1.3 Technology/Service Providers

This includes companies which provide aviation technologies and services which are applicable to the bushfire context as well as companies which provide the necessary supporting elements to enable the aforementioned technologies. Fire technology product developers and service providers are a key stakeholder as a commercially viable marketplace is essential for quality products and competitive prices.

4.1.4 Firefighting Aircraft Providers

This stakeholder group constitutes existing aerial firefighting aviators. The proposed introduction and expansion of uncrewed aviation into the bushfire context poses a hazard to existing crewed operations that must be managed. Firefighting Aircraft Providers constitute all existing aerial firefighting capability and their input into this project ensures that the individuals exposed to the potential risks of uncrewed aviation are consulted and informed.

4.1.5 Australian Federal Government Agencies

There are a number of federal government agencies which have significant strategic impact on the adoption of RPAS technology within the bushfire context. These are namely:

- **CASA.** The Civil Aviation Safety Authority is a government body that ensures the safety of aviation in Australia. Within the context of this project, their role is to set aviation safety standards and ensure compliance with these standards. Remote aircraft operators will also apply to CASA for flight authorisations that permit specific operations such as flight beyond visual line of sight.
- **NEMA.** National Emergency Management Agency (NEMA) is Australia's National Disaster Management Organisation. NEMA manages the Australian Government Disaster Response Plan (COMDISPLAN) under which states and territories may seek Australian Government assistance when the scale of an emergency or disaster exceeds or exhausts the jurisdiction's response capacity and capabilities, or where resources cannot be mobilised in sufficient time. NEMA delivers programs, policies and services that strengthen Australia's national security and emergency management capability.
- **DITRDCA.** The Department of Infrastructure, Transport, Regional Development, Communications and the Arts (DITRDCA) is a department of the Australian Federal Government responsible for delivering Australian Government policy and programs for infrastructure, transport, regional development, communications, cultural affairs, and the arts.

4.1.6 Non-Government Organisations

Australia also has several non-government organisation that play key roles in coordinating fire management activities in Australia.

- **AFAC.** Australasian Fire and Emergency Service Authorities Council is the National Council for fire and emergency services and supports the sector to create safer, more resilient communities. AFAC drives national consistency through collaboration, innovation and partnerships to deliver enhanced capability by developing doctrine and supporting operations.
- **NAFC.** National Aerial Firefighting Centre is a business unit of AFAC and exists to provide effective support for the combating of bushfires through national co-operative arrangements for provision of aerial firefighting resources.

4.1.7 Indigenous Peoples

Indigenous Peoples and communities across Australia continue to actively manage their traditional lands and waters using cultural land management practices. These practices, also known as Caring for Country, include the application of cultural burning, which is focused on the improvement of landscapes and ecosystem function through the careful implementation of fire practices that have been developed and honed over thousands of years. Following the 2019-2020 Black Summer Fires, government and public support for cultural burning as a tool to mitigate against wildfires has increased. Despite this increased attention, opportunities for Aboriginal Ranger groups and communities to implement cultural burning remain limited due to limited funding and bureaucracy, particularly in the populated metropolitan and semi-rural areas of southeastern Australia. Aboriginal fire practitioners are increasingly utilising RPAS technology to monitor cultural burns in real time, produce pre and post-burn maps, and to understand how the characteristics of flora and fauna respond to cultural fire.

4.1.8 Research Institutions

Research into RPAS technology is driven by a range of research institutions, including universities and other research organisations. This stakeholder group was engaged to gain insight into RPAS technology and inform the project team of what is possible in the future. Their contributions also feed into Section 2 of the report, which presents a literature review of the applications of RPAS.

4.1.9 Philanthropy

Philanthropic stakeholders are individuals or organisations that provide resources and support to advance innovative aviation solutions for societal benefit. Their involvement accelerates innovation and ensures responsible development of aviation technologies for positive societal impact. Understanding the areas of fire management which are receiving philanthropic investment provides insight into which technologies are expected to advance without government intervention.

4.1.10 Utilities and Infrastructure

Companies and government agencies which own and operate critical infrastructure have significant interest in the improvement of bushfire management. These high value assets can have a significant cost of replacement and provide critical services to communities. Infrastructure companies have already begun to utilise RPAS for cases such as wind turbine inspection or power line surveying, showing an appetite for innovation. The users for RPAS within bushfire applications may be the fire agencies and land managers, however, utility and infrastructure operators, as the customers of the firefighting services, have significant interest in improved outcomes. Consultation with US based stakeholders has shown that infrastructure companies can see positive returns through fire response investment. Therefore infrastructure and utility providers are likely to have financial incentives to support innovations such as the uptake of RPAS within bushfires as they show promise in reducing fiscal losses and the outage of critical services.

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4.2 National Centres and Initiatives

There are several major centres or initiatives in Australia actively investigating, evaluating and demonstrating new bushfire science and technology. The present summary focuses on those that are particularly active in RPAS technology.

Firetech Connect (coauthor of roadmap), is a program funded by the Australian Federal Government focused on accelerating the real-world adoption of promising technologies. Their efforts centre around extensive operational trials, particularly the Fire Air Traffic Management (FATM) trials, which aim to seamlessly integrate RPAS into airspace shared with crewed aircraft during bushfire events. Leveraging a dedicated Bushland Lab and a network of over 150 technology providers, Firetech Connect can test and evaluate RPAS capabilities in real-world conditions, simulating bushfire scenarios and facilitating the trialling and testing of emerging technologies. This practical approach is further strengthened by strong collaborations with key stakeholders like QFD, SES, Airbus and other private sector organisations.

The Bushfire Research Centre of Excellence (BRCoE) (coauthor of roadmap) supported by Optus and the Australian National University (ANU) is dedicated to developing, demonstrating, and evaluating innovative technological solutions for bushfire management. Their goal is to provide expert guidance and drive scientific and technological advancements at the highest levels in Australia. BRCoE actively collaborates with industry partners to explore and develop cutting-edge technologies and works alongside government agencies to shape policy and regulatory frameworks across various areas of bushfire management. One such area of focus is RPAS technology, which the Centre has been instrumental in advancing. BRCoE provides independent and objective assessments of emerging technologies and serves as an invaluable resource for evaluating the potential of new solutions. The Centre also plays a crucial role in disseminating knowledge and best practices through publications, workshops, and presentations, fostering a deeper understanding of these technologies within the broader bushfire management community

Operational use of an RPAS with an EO/IR camera for mapping during a prescribed burn at Bullen, ACT (Photo: Gary Hooker).

4.3 International Landscape and Context

Adoption of RPAS technology for bushfire management is not an exclusively Australian issue. The United States is a hotbed of innovation in this field, with NASA's ambitious Advanced Capabilities for Emergency Response Operations (ACERO) project at the forefront. This collaborative effort with the US Forest Service and California Department of Forestry and Fire Protection (CAL FIRE) aims to create a comprehensive system using RPAS for persistent 24/7 wildfire surveillance, improved communication infrastructure in fire-prone regions, and targeted suppression tactics. They are exploring both small, tactical RPAS and larger, high-altitude platforms for extended missions, showcasing the versatility of RPAS in tackling wildfires. Other agencies in USA involved in RPAS innovation include United Aerial Firefighters Association (UAFA) and Bureau of Land Management (BLM).

Private companies are also playing a significant role in the US. A number of companies are pioneering drone-assisted fire suppression, developing specialised RPAS capable of delivering fire retardant with pinpoint accuracy. This technology represents a significant leap forward in firefighting safety and efficiency compared to traditional aerial methods. Beyond these high-profile initiatives, numerous state and local fire agencies across the US are progressively incorporating RPAS into their operations, experimenting with their use for real-time fire mapping, damage assessment, and search and rescue efforts.

In Canada, the British Columbia Wildfire Service is at the forefront of utilising RPAS for wildfire detection and mapping. They deploy RPAS equipped with high-resolution cameras and advanced sensors to create detailed fire maps and pinpoint hotspots, enhancing situational awareness and facilitating more informed decision-making. They are also exploring the potential of using RPAS for initial attacks on small fires, particularly those in remote locations, aiming to contain fires before they escalate.

Europe is steadily advancing in wildfire management through innovative RPAS applications, particularly in Mediterranean regions. National agencies in Spain, Portugal, Greece and France are actively incorporating RPAS into wildfire response strategies, using them for diverse tasks such as aerial surveillance, post-fire damage assessment, and direct support for ground crews. These applications highlight the adaptability of RPAS in managing wildfires across various terrains and conditions.

In Spain, drone-based photogrammetry has achieved over 80% accuracy in classifying vegetation and fuel types for fire behaviour models, proving invaluable for both planning and understanding fire dynamics. Additionally, RPAS data plays a critical role in fuelbreak planning near urban areas, where combined multispectral and LiDAR data improve vegetation management and reduce fire risk. Collectively, these initiatives underscore Europe's commitment to enhancing wildfire preparedness and forest management through RPAS technology.

These international efforts demonstrate a growing global recognition of RPAS technology's power to transform wildfire management, leading to a more data-driven, technologically sophisticated, and proactive approach to tackling this increasingly pressing global threat.

4.4 Summary of Key Themes

4.4.1 Collaboration

Under Australia's constitutional arrangements, state and territory governments have primary responsibility for emergency management within their jurisdiction, including bushfire. This results in differences in capabilities and procedures across borders which can hinder collaboration. CASA, as a federal body, has a responsibility to regulate aviation safety and ensures an acceptable level of safety. The increasing involvement of civilian RPAS operators providing services to emergency agencies adds further complexity, making coordination within the airspace above an active fire a significant challenge.

4.4.2 Commercialisation

Technology and service providers have expressed significant difficulty in identifying clear pathways to commercialisation within the fire industry. In many cases the intended user of the product or service may not be closely tied with the procuring agency. Industry has also expressed frustration with the requirement to conduct frequent product demonstrations to various agencies, rather than market to a central body. In the absence of clear pathways to commercialisation, technology providers have pivoted to less risky industries, such as mining and infrastructure, where they can market from Business-to-Business with less risky procurement strategies. This results in the fire industry having limited access to fit-for-purpose technology and a less competitive market for services, allowing providers to charge more.

Agency and Land management representatives have noted that the products and services offered by industry are largely designed with another market in mind and are prioritising products that do not solve the priority issues for the agencies. There are also limited opportunities for demonstrating the operational readiness and integration of products offered by industry prior to the procurement, which can often result in the procurement of isolated technologies that do not integrate into existing systems.

4.4.3 RPAS Resourcing Constraints

Financial and human capital constraints within the fire agencies limit the capacity to pursue emerging RPAS technologies. Procurement and sustainment of RPAS requires funding through extant budgets as well as staff to absorb RPAS related duties secondary to their core duties.

4.4.4 Education on RPAS Capabilities

As an emerging technology that is rapidly developing, the fire agencies and land managers identified that the role of RPAS within the industry is not well understood or documented. Education through technical demonstrations as well as collaboration with other agencies provides insight into how RPAS are currently being used. With increasing exposure to the technology, fire agencies and land managers are actively expanding and developing the use cases for RPAS technology, for example, fitting a spotlight for night operations, etc.

4.4.5 Perception of RPAS within the Aerial Firefighting Industry

Discourse around the introduction of RPAS into fire management, particularly in use cases which involve a blended airspace (crewed and uncrewed aviation within the same vicinity) are particularly sensitive, as the established crewed aviation industry is exposed to both the safety risk of mid-air collisions as well as the business risk of increased competition. The perceived business risk can be managed through messaging that uncrewed aviation is not replacing crewed aviation but rather augmenting existing capabilities. Perception of uncrewed flight operations is typically that of a lower standard to traditional crewed aviation and confidence in the emerging industry must be established before a blended airspace is considered. This can be done through flight trials and demonstrations.

PART 5: Analysis of Challenges

This report has provided the technical and socio-economic considerations of emerging aviation uptake in bushfire management. Part 5 of the roadmap reconsiders the earlier content presented through the lenses of Leadership and Organisational Challenges, Operational Challenges, Innovation Challenges, and Commercialisation Challenges. The following analysis underpins the recommendations made in Part 6.

5.1 Leadership and Organisational Challenges

Executive leadership of federal and state based agencies and organisations have significant roles to play in setting strategy and driving the changes necessary to improve the operational uptake of RPAS within agencies. This section examines the key challenges to be addressed by leadership.

5.1.1 National leadership

Whilst each state based fire and land management agency has ownership of their uncrewed aviation programs, there are many commonalities across the States. This is evidenced in the multitude of RPAS trials coordinated by various state agencies to investigate the feasibility of RPAS operating BVLOS. A working group that leads the charge in solving the challenges which are common across the States, such as BVLOS operations, will minimise duplicated effort, maximise information sharing and allow for optimisation of resources. This working group should be led by a central organisation and include representatives from fire agencies, industry, research institutions, and regulatory bodies. The focus of the working group would be to develop and implement a national RPAS integration strategy, coordinating efforts across agencies, and securing funding.

5.1.2 Agency Executive Sponsorship

Adoption of RPAS within fire and land management agencies and organisations requires commitment of human and fiscal resources to realise the significant capabilities offered by the technology. Remote systems aircrew interviewed identified the difficulty in attempting to drive adoption from the bottom up. This was particularly prevalent in the agencies of the smaller economy states and volunteer organisations, where budgets are extremely tight and capacity for bottom-up driven innovation is near impossible. Sponsorship of RPAS programs from executive leadership with the capacity to support through the allocation of resources and profile is critical in the successful uptake of such technology.

5.1.3 Organisational Culture

Fire and land management agencies have a societal responsibility to manage fire to protect property and life. By their nature, these agencies are operationally focused and often resource constrained, especially during fire season. Despite these constraints, these agencies have an established record of successful operational innovation in aerial technology. For example, agencies have championed the use of crewed aircraft in water bombing, logistics, and ISR for many years, and more recently have been at the forefront of the adoption and use of small RPAS for over the hill ISR activities at the brigade level. Incorporating such technology into operational activity involved changes to bushfire fighting methodology and operations, combined with adoption of the new technological capability to achieve improved fire outcomes.

However due to their exposure to public scrutiny and focus on operational capability, as well as their budget constraints, these agencies have a strong reliance on traditional methods and are risk averse to adopting new technologies. This stems partly from an understanding and confidence in established procedures along with reporting requirements that emphasise existing operational capabilities. In addition, some resistance to automation and robotics stems from concerns about potential job displacement within fire agencies. Addressing these concerns through clear communication, retraining programs, and highlighting the complementary nature of these technologies will be crucial.

The survey responses indicate that aerial firefighting aircrew expect an increased uptake of RPAS but are cautious of how the introduction is managed and the risk they may be exposed to. This stakeholder group has significant influence within the industry and it is critical that aerial firefighting aircrew are engaged and consulted on RPAS adoption.

Overcoming the perception of RPAS as hobby technology that introduces additional risks to crewed aviation requires a clear argument that focuses on the capability value and potential risk mitigations offered by increased RPAS uptake. Motivating large organisational changes requires executive sponsorship delivered in a strategy with a clear capability benefit to be realised.

5.2 Operational Challenges

The operation of RPAS in bushfire applications comes with a number of challenges which are discussed in this section.

5.2.1 RPAS Operating Strategy

Although many fire agencies and land managers have documented strategies for the implementation and operation of RPAS, these are often not well coordinated between jurisdictions. A key finding from the stakeholder engagement was the need for a high level strategy document at the state agency level, set by agency executives, and coordinated with other Australian agencies that identifies the capability needs for RPAS and outline how these capabilities will be resourced and staffed.

Currently most RPAS operations utilise multi-rotor RPAS that operate within visual line of sight. These simpler operations are staffed by full-time Remote Pilots, volunteers or, more often than not, a firefighter performing Remote Pilot duties secondary to their primary duty. This model is limited to local ISR operations with small quadrotor style RPAS.

Representatives of fire and land management agencies identified the need for more complex operations such as fixed wing or VTOL aircraft operating BVLOS, however, these more complex flying operations attract significantly more overheads in training and maintaining proficiency.

Utilising external service providers for RPAS capabilities can reduce overheads but also decentralises control of the capability. An RPAS strategy document will provide guidance on the RPAS capabilities required as well as how these will be procured and sustained. This strategy will support the RPAS crews within the agencies as well as inform industry service providers as to what the agencies require.

5.2.2 RPAS Flight Authorisations

Specific approvals issued by CASA are required for certain RPAS operations, namely operating a RPAS beyond visual line of sight (BVLOS) of the pilot and operating a RPAS over 400ft above the ground. CASA is inundated with flight authorisation applications. At the time of writing, CASA has a backlog of 400 applications of varying complexity, with some taking months to approve. Many applicants are requesting authorisations beyond what is required and are often failing to deliver a credible safety case, taxing the assessment system and causing additional delays. Applications are processed on a first-come-first-serve basis, unless there is a genuine emergency, in which case CASA has procedures to expedite applications of national importance. RPAS use cases identified for pre and post fire in Part 2 are not classified as emergency scenarios and will not be prioritised. The delay in obtaining flight authorisations greatly hinders the ability of agencies and industry to test and evaluate RPAS for bushfire application, causing significant commercial uncertainty and procurement risk for both parties.

The US Congress, in their reauthorisation of the Federal Aviation Administration, has tasked the FAA with developing a plan for the use of uncrewed aircraft systems in bushfire response (see public law 118-63). We also note that CASA is working towards streamlining BVLOS operations. The regulatory barrier of flight authorisations was cited in both the Survey within Annex B and the Australian Association for Uncrewed Systems' Australian RPAS Industry Survey 2024, as the one of the leading risks to the adoption of RPAS.

There is an opportunity for the development of standard scenarios associated with firefighting RPAS technology use. For example, the airspace directly above a fire or prescribed burn could be considered atypical airspace[1] where access is restricted and the fire agency maintains control of both the ground and air participants. Establishment of standard scenarios and procedures that providers can leverage to simplify applications processes, identifying clear priorities for CASA associated with sensible BVLOS applications that use these scenarios, and working with sufficiently mature service providers to document and manage these scenarios, can mitigate risks in the accreditation and streamline and expedite flight authorisations for bushfire applications.

1 As defined in CASA Standard Scenario Application and Documents - Guidance Material, Version1.0 - August 2021

5.2.3 Standardisation

Standardisation is key to enabling interoperability, optimising commercialisation and maximising national benefit. Bushfires do not adhere to borders and collaboration across agencies and industry is critical to the future impact of RPAS technology in bushfire applications. As an emerging industry, RPAS can be introduced into bushfire management through the development of national standards which enable integration and interoperability for cross-agency efforts while allowing different states to work with different providers and different technology in the spirit of federation. Fire and Land agency stakeholders identified AFAC and in particular NAFC as a national organisation that has the greatest stake in this domain. With many RPAS programs in their infancy, there is an opportunity for government and industry leadership to establish best practices and help accelerate the adoption of RPAS technologies.

Standardisation and adoption of standards is a complex multifaceted process with far reaching implications to commercialisation and technology development. Development and adoption of standards requires a coordinated industry wide effort and typically takes years. This can be accelerated by appropriate government leadership and by affording priority to key challenges. For example, standardisation of procedures and processes for operational command of RPAS activities across geographic borders and organisational boundaries. There is also a need for standardisation of procurement and service provision nationally, analogous to the role that NAFC plays in managing existing crewed vehicle aerial firefighting services. Finally, there is a need for standardisation of technology for interoperability of RPAS in fireground airspace, and data formats to allow integration of data in different operation and data analysis centres.

5.2.4 Airspace Integration

Exploiting the full suite of RPAS use cases requires the integration of uncrewed systems into crewed airspace. This will require the adoption of technology aids as well as the development of procedures to enable a blended airspace. Technologies such as Electronic Conspicuity (the addition of electronic beacons that broadcast the RPAS position to neighbouring vehicles either directly or through internet connectivity) and detect and avoid (algorithms that allow RPAS to take coordinated evasive action to avoid collision with other vehicles, both autonomous and crewed) will be developed and introduced as operational controls to minimise the risk to crewed aircraft. Procedures will need to be developed and tested in both trial and operational environments. The airspace above an active fireground is congested, dynamic and further complicated by extreme weather conditions such as high winds, heavy smoke and intense heat. Introduction of RPAS into this airspace must not compromise safety or capability of existing crewed platforms. Developing a safe, blended airspace will be challenging and require a concerted effort from industry, CASA, firefighting aircrew and fire agencies. Leading this effort is beyond the scope of any individual fire agency and should be led by a national test centre.

5.3 Innovation Challenges

Encouraging and supporting innovation is critical to enabling RPAS technology to maximise its contribution to bushfire fighting in Australia in the coming years. Innovation goes beyond research and development of new technology—though that is an important part. It involves combining two or more technologies to create new capabilities that address real societal needs in a scalable way. As such, enabling innovation is about creating an environment that start-ups and other companies can try out combinations of technologies in different ways to demonstrate capability, and where customers can see and evaluate the potential of that capability to address their needs, before committing to costly investment.

5.3.1 Operational Innovation in Aerial Firefighting

Fire and land management agencies have an established record of operational innovation and there are already many cases of RPAS systems incorporated into fire management activities championed by agencies. For example, agencies have adopted small RPAS for over the hill ISR activities at the unit level and there are active trials in using medium scale quadrotors for incendiary deployment. A key observation is that this technology was already commercially available before the agencies were involved in the innovation journey. The innovation occurred in the integration of the technology into the new firefighting operations and methods.

There is a distinction between operational innovation and technological innovation.

- *Technological innovation* is associated with developing new technological capability appropriate for a certain scenario.
- *Operational innovation* is associated with integration of new technology into real-world operational capability.

For example, small scale ISR quadrotor RPAS were developed for general inspection and surveillance tasks and are commercially available. Incorporating these platforms into active fire management is not a trivial step and should not be underestimated. However, the process of integrating this technology into fire management procedures is one of operational innovation.

The challenge facing the industry is how to support the necessary steps of targeted technological innovation in order to develop demonstrated systems capability that can be evaluated by fire agencies and lead in turn to operational innovation and improved outcomes.

5.3.2 Technological Innovation in RPAS for Firefighting Applications

New RPAS technology, such as discussed in Part 2, requires research and development to drive technological innovation and create products that demonstrate new capabilities. To maximise the potential benefit from RPAS technology in emergency services and firefighting applications as quickly as possible, there is a need to create a dynamic and supportive environment for RPAS technological innovation in Australia. The existing agencies AFAC, NAFC, and the state fire agencies are not the appropriate organisations to drive this innovation, although they naturally have an oversight role.

Technological innovation is risky. New technology may lead to capability demonstrations that are unconvincing or simply fail, the technology may be too costly to implement, or may not scale effectively, etc. Companies involved in innovation will often have multiple markets targeted for their technology and will not be willing to commit all their resources simply to demonstrating capability just for one market. The risk of failure and the ability to quickly pivot to new products or new markets is fundamental in successful technological innovation. Operational organisations such as the fire agencies, NAFC or AFAC operate under significant public scrutiny and cannot afford to support exploratory demonstrations of technology that does not have a high chance of success. They cannot afford to support technological innovation that may shift to a different market, fail to achieve the necessary outcomes, or simply not deliver significant impact.

Since existing organisations are not the appropriate mechanisms to support new technological innovation, there is a need to create a new framework and organisational structure in Australia to nurture and enable this activity to achieve the potential gains that RPAS technology can bring to fire fighting. Such an organisation would come under the auspices of the existing organisational structure of NEMA, AFAC and NAFC, however, it would need to be an independent entity that has the goal of bringing technology to the point of demonstration and evaluation. This organisation does not need to be enduring, the key period for enabling RPAS technology in firefighting is now and the next five years.

The primary role of a new organisation would be to provide an environment for Australian companies undertaking innovation in RPAS technology to demonstrate capability. Its secondary roles would be to guide innovators and their companies towards developing high value technological capabilities for fire agencies, and to be a trusted partner to Australian fire agencies in evaluating the real capabilities the technology demonstrated. This perspective is further supported by the next section.

5.3.3 Test and Evaluation

In order to mitigate procurement risk, Fire and Land management agencies have identified the requirement for test and evaluation of RPAS products and services to assess their fitness for purpose. This process can be complex and challenging, requiring scarce agency resources.

Technology and Service providers have also expressed frustration with these requirements as it is often simplified to a demonstration with no clear path forward and is repeated for each individual agency.

To effectively mitigate procurement risk, an Australian test range is needed along with a national body that can conduct test and evaluation activities on behalf of the agencies for RPAS technologies and services with fire applications. This national body would also alleviate duplication of test events which are costly to industry.

5.3.4 Data Product Integration

The data collected by RPAS is only as valuable as its integration into existing fire management systems. Developing seamless data pipelines and suites of data analysis tools that allow real-time data from RPAS to be incorporated into geospatial platforms, fire behaviour models, and incident command systems, is essential for informed decision-making and improved situational awareness.

The technology for centralised data analysis and data product integration is not available commercially-off-the-shelf at the moment. Integrating data requires firstly real-time connectivity not only for the RPAS but for field based operators. Equally important is the development of suites of analysis algorithms that can convert raw data into actionable intelligence and disseminate this information to multiple users in real-time through existing fire intelligence platforms. Analysis that draws on multiple diverse data streams is exponentially more informative than single data stream products that must be interpreted by humans to find correlations and meaning. To realise the true benefits of RPAS technology, it is critical to share data and invest in the research and development of data analysis products targeted at the fire industry and more general emergency management.

5.3.5 Datasets

Public ownership of data collected by government funded activities should be a fundamental principle of all contracts in fire RPAS technology. Machine learning and Artificial Intelligence products require large amounts of data to be trained but offer significant advantages in many perception and classification tasks. Many government sponsored trials are underway collecting data and investigating the viability of products in fire applications. There is significant value in the datasets collected during these trials. However, there is a general lack of awareness in the fire industry of the value of this data and a number of companies have been paid to collect data in trials that they now own and cannot be accessed by the agency that paid for the trial. Allowing publicly funded data to be privately owned gives the company that collected the data a competitive advantage at taxpayers cost and will lead to second best outcomes in the long term. Clear data sharing agreements and governance frameworks are essential to address these issues.

5.4 Commercialisation Challenges

There are a number of challenges to the development of sustained economic activity to provide RPAS technology into the fire industry. The bushfire technology sector faces several unique commercialisation challenges, hindering the widespread adoption of potentially life-saving innovations. Here are some of the most significant obstacles:

5.4.1 Entry to Market

Market entry for commercial RPAS products and services in the Fire emergency is challenging. For every RPAS operator or manufacturer interviewed during this project the commercialisation pathway within the fire industry was uncertain.

As discussed in Part 4, the fire agencies do not have the resources to support industry when approached, nor do they fully understand the technological capabilities and how they can meet their needs. Adding the context of regulatory barriers, lack of national champion and documented strategic direction from the agencies, RPAS providers are struggling to find a way into the fire industry, and more broadly into the emergency services sector.

The bushfire market is highly fragmented, with multiple fire agencies, land management organisations, and government departments operating independently. This creates a complex and time-consuming sales process for technology providers, requiring them to navigate diverse procurement processes and address specific needs across various jurisdictions. Technology and service providers are pivoting away from fire management despite the clear potential of RPAS technology and focusing on business to business engagements where the pathway to entry is clear and the commercial risk is significantly reduced. These barriers to entry ultimately reduce the products and services available to fire and land agencies which are competitive and fit for purpose.

5.4.2 Funding for RPAS

Procurement and sustainment of RPAS within the fire agencies will require prioritisation within already limited budgets. This allocation of resources into a developing technology with moderate upfront costs may prove too risky for agency leadership. The procurement model for aerial firefighting assets currently relies heavily upon NAFC and their Arena Software. This software allows agencies to access and task accredited aerial firefighting suppliers alleviating the agencies of significant procurement process and costs whilst permitting access to capability. This software could be upgraded to include a similar process for the tracking of qualified and accredited RPAS operators.

Developing, testing and integrating RPAS technologies into the bushfire management industry is currently funded through sporadic government grants. Bidding and securing these grants takes significant resources and generally only supports a discrete element of the development process. Stakeholder engagement also identified several programs where government grants were funding similar activities, such as beyond visual line of sight RPAS operations trials in NSW, QLD and VIC. A national working group which is charged with tackling the priority issues for the fire and land agency adoption of RPAS could coordinate these development efforts and optimise the outcomes from grant expenditure.

5.4.3 Seasonal Nature of Fire

The seasonal nature of bushfire risk creates fluctuating demand for technology solutions. This can make it challenging for companies to sustain business operations year-round and secure consistent revenue streams.

RPAS capabilities, either organically held within the fire and land management agencies, or externally contracted need to be multi-use and not specifically dedicated to fire applications. In particular, land management agencies identified the requirement for multi-use platforms as their responsibilities are broader than fire management.

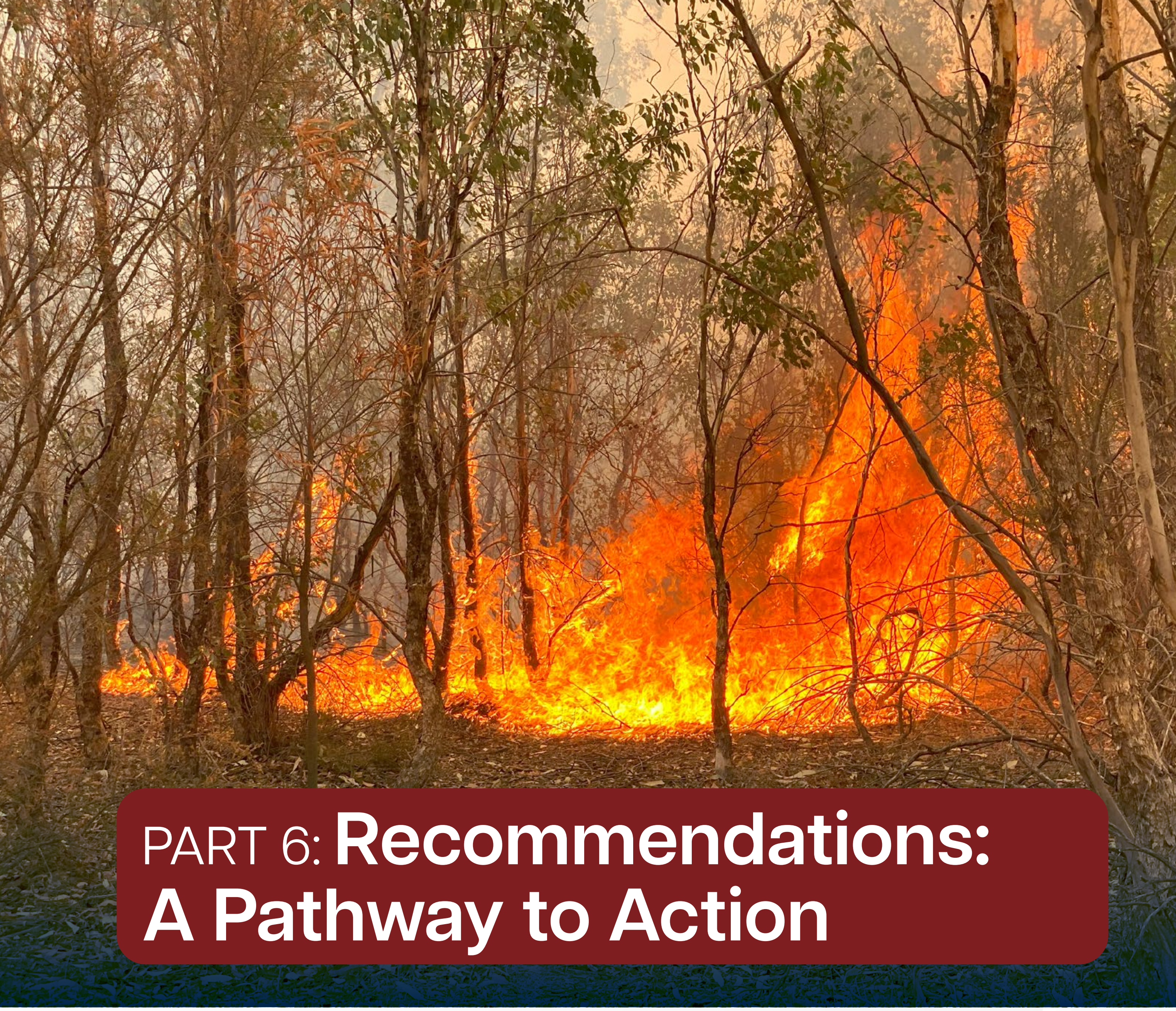
Multi-use platforms will result in competition between the off-season customers of the RPAS products and the fire agencies during fire seasons. Fire agencies shall need to assess the viability of dedicated capabilities versus the reduced control of pooled resources. This challenge not only affects the level of service but also the quality of product as the market for RPAS which are specifically designed for fire application is less commercially viable.

5.4.4 Quantifying the value of early detection and suppression

Early detection and suppression of a bushfire has huge socio-economic benefits but has a very low political and publicity profile. Many of the RPAS use cases identified in Section 2 are associated with prevention use cases and face challenges in attracting ongoing funding.

Technology and Service providers have identified a number of stakeholders with direct commercial benefit in fire prevention, such as infrastructure and insurance companies. Project interviews identified an example where a US based infrastructure company has funded a dedicated crewed aerial fire response capability year-round and is seeing positive returns on investment.

Quantification of carbon credits associated with preventing a large fire may open financial opportunities to support early detection and suppression. No formal processes to quantify or document savings associated with early detection and suppression of fires exist in Australia at this time. Development of an accredited process to quantify benefit from early detection of bushfires and specifically the value of RPAS technologies in such activities is a key step in evaluating value from such activities.



PART 6: Recommendations: A Pathway to Action

This section presents a comprehensive set of recommendations for policymakers, industry stakeholders, and fire agencies to guide the integration of RPAS technology into Australian bushfire management. We have starred "*" four recommendations 6.1.1, 6.1.2, 6.2.1, and 6.3.1, that we consider to be the most important recommendations. These four recommendations support two key initiatives:

1. Identifying a champion [R6.1.1] and strategic plan [R6.1.2] in each of the state fire agencies for RPAS technology adoptions.
2. Establishing a technology centre [R6.3.1] that manages a test range facility [R6.2.1] to provide test and evaluation of RPAS technology for fire management applications.

Focusing on these two initiatives, supported by the other recommendations, will go a long way to accelerating the adoption of RPAS technology in fire management in Australia.

6.1 Recommendations on Leadership and Organisation

Adoption of new RPAS technology depends on strong leadership at the appropriate levels within the key agencies and organisations.

R6.1.1* Each State Fire Agency to identify an executive champion to promote RPAS technology adoption.

This role must have authority to provide resources to purchase and support systems. It would act to foster operational acceptance of RPAS technology at the state level.

R6.1.2* Each State Fire Agency to develop a high level strategic plan for adoption of RPAS technology.

These plans would define RPAS capabilities required, outline the procurement processes, and plan how the capability will be sustained.

R6.1.3 Improve communication around RPAS technology between state fire agencies, NEMA, AFAC, NAFC, CASA, DITRDCA, industry, and other national fire management bodies via an appropriate group or mechanism.

This group could be part of a wider emergency services group focused on RPAS technology. It would be tasked to:

- Develop and maintain a national emergency services RPAS technology strategy: This strategy should outline clear priorities, funding mechanisms, and pathways for commercialisation,
- Provide CASA with guidance on prioritising flight authorisations and certifications for RPAS activities in bushfire applications.
- Initiate and facilitate industry led working groups to develop nationally accepted procedures and standards for RPAS technology for emergency and bushfire management applications.
  - » standardisation of procedures and processes for operational command of RPAS.
  - » standardisation of procurement and service provision of RPAS technology.
  - » standardisation of technology for interoperability of RPAS in fireground airspace.

R6.1.4: Establish a National Emergency Services Forum in Remote Piloted Aircraft Systems Technology.

This forum would bring together representatives from fire agencies, State Emergency Services (SES), land management organisations, insurance companies, RPAS technology providers, researchers, and regulators, etc, on a regular basis. It would serve as a platform for open dialogue, needs identification, technology showcases, and collaborative project development. For example, a forum in parallel with a major symposium such as the annual AFAC conference.

6.2 Recommendations on Operations

Developing a shared understanding of how RPAS technology and data can effectively contribute to and augment bushfire fighting activities is an ongoing process. Common use cases with high value provide guidance to industry and streamline approval processes shortening the time to market for new technologies. Public data is a key enabler for entry of new companies to existing and new markets as well as a crucial requirement to benchmark existing products.

R6.2.1* Strengthen facilities for testing, development, and demonstration of RPAS capability for fire management applications through an Australian test range facility open to companies, fire agencies, research institutes and academia.

Such a facility will significantly shorten development times for companies engaged in RPAS technology innovation. Providing standard use case flight authorisation will further shorten lead times.

R6.2.2 Identify common fire management use cases and develop standardised operational procedures to streamline CASA approvals for RPAS operations.

Public documentation of standard use cases will significantly simplify and improve outcomes from the CASA approvals process and shorten lead times for new companies entering the market.

R6.2.3: State agencies to place priority on RPAS uptake with easy use cases to build familiarity and confidence in the new technology.

Tackling the easy cases will build confidence in the new technology while providing support for the emerging market.

R6.2.4 Establish a data storage capability for Australian bushfire (or more generally emergency services) data. Access should be available to all agencies, companies, and the public.

There is a role for an agency, possibly AFAC for fire related data, or NEMA if the data is more generally for all emergencies, to manage a data facility for the enormous amount of data that will become available as more autonomous systems move into firefighting roles and more generally into emergency support roles. Making this data available publicly is critical to supporting competition in technology and service providers and ensuring the best and most innovative products for fire agencies. While access to this data may include cost-recovery fees, it must remain open and unrestricted by commercial confidentiality agreements.

R6.2.5 Develop standard terms and conditions for public data ownership in contracts involving fire RPAS technology used for government funded activities.

Standard terms and conditions can be developed by the appropriate legal teams at the state level based on advice from agencies, academia and industry bodies to ensure that data collected using RPAS technology remains available for public good without impacting commercial viability of companies.

6.3 Recommendations on Innovation

Existing government agencies have a demonstrated record of operational innovation but are not set up for technological innovation. Enabling and energising technological innovation for bushfire RPAS technology requires a new framework of support.

R6.3.1* Accelerate the translation of RPAS technology into operation in Australia by supporting a technological centre targeted at test, evaluation, development to support bushfire RPAS technology.

Such a centre would:

- Manage the test range proposed in R6.2.1.
- Undertake test and evaluation of RPAS technologies for fire-fighting applications.
- Undertake research and development into data integration protocols, standards and software.
- Lead development of standards for integrated airspace, communications protocols, and data storage.
- Share knowledge across the fire industry in Australia
- Build trust between stakeholders in RPAS technology.
- Provide guidance for capability requirements to government and RPAS technology companies.
- The lifetime for such a centre is in the order of 5 years.

6.4 Recommendations on Commercialisation

The successful integration of RPAS technology into Australian bushfire management hinges on a thriving commercial RPAS industry that can sustainably provide innovative and fit-for-purpose solutions to fire agencies.

R6.4.1 Establish a facilitated engagement mechanism for industry and fire agencies

Establishing a top-down/bottom-up formal process to support industry fire agency engagement.

- Top-down: A documented set of high-value use cases targeted at RPAS technology for bushfire operations. This document would provide guidance to innovations companies as to what capabilities the fire agencies would value.
- Bottom-up: A more formal process by which companies with innovative solutions can demonstrate new capability, conduct requirement gathering sessions, and present new and/or novel products.

By establishing formal mechanisms for this engagement it will reduce the load on agency champions replacing case-by-case demonstrations of components of solutions from multiple companies by integrated demonstrations of capability. For technology companies it will provide a mechanism to pitch to a wide range of potential customers across multiple states and agencies.

R6.4.2 Encourage Multi-Use RPAS Capabilities and Partnerships

Promote the development and adoption of multi-use RPAS platforms that can serve a variety of purposes beyond bushfire management, such as land management, environmental monitoring, and emergency response in other contexts.

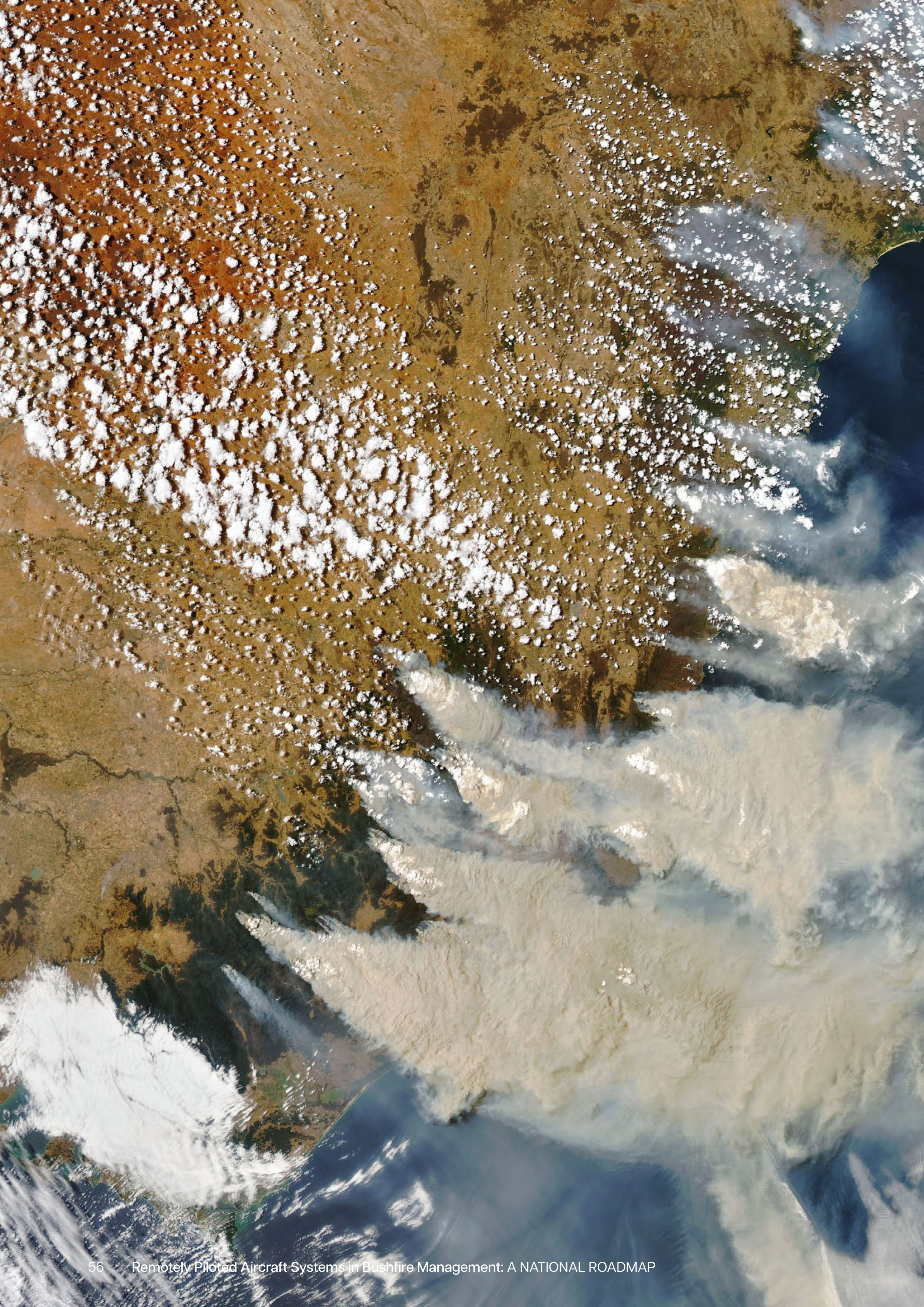
R6.4.3 Fund the research and development of an accredited process to quantify the benefit accrued in early detection and suppression of fires.

Quantifying the benefit accrued from suppressing a fire before it grows too large to control is a key step in the ongoing support of all new technology, including RPAS, for the management of bushfires.

R6.4.4 Develop a National RPAS Procurement Framework

Leveraging the successful software model used by NAFC for procuring crewed aerial firefighting services, create a dedicated platform for RPAS suppliers. This platform would:

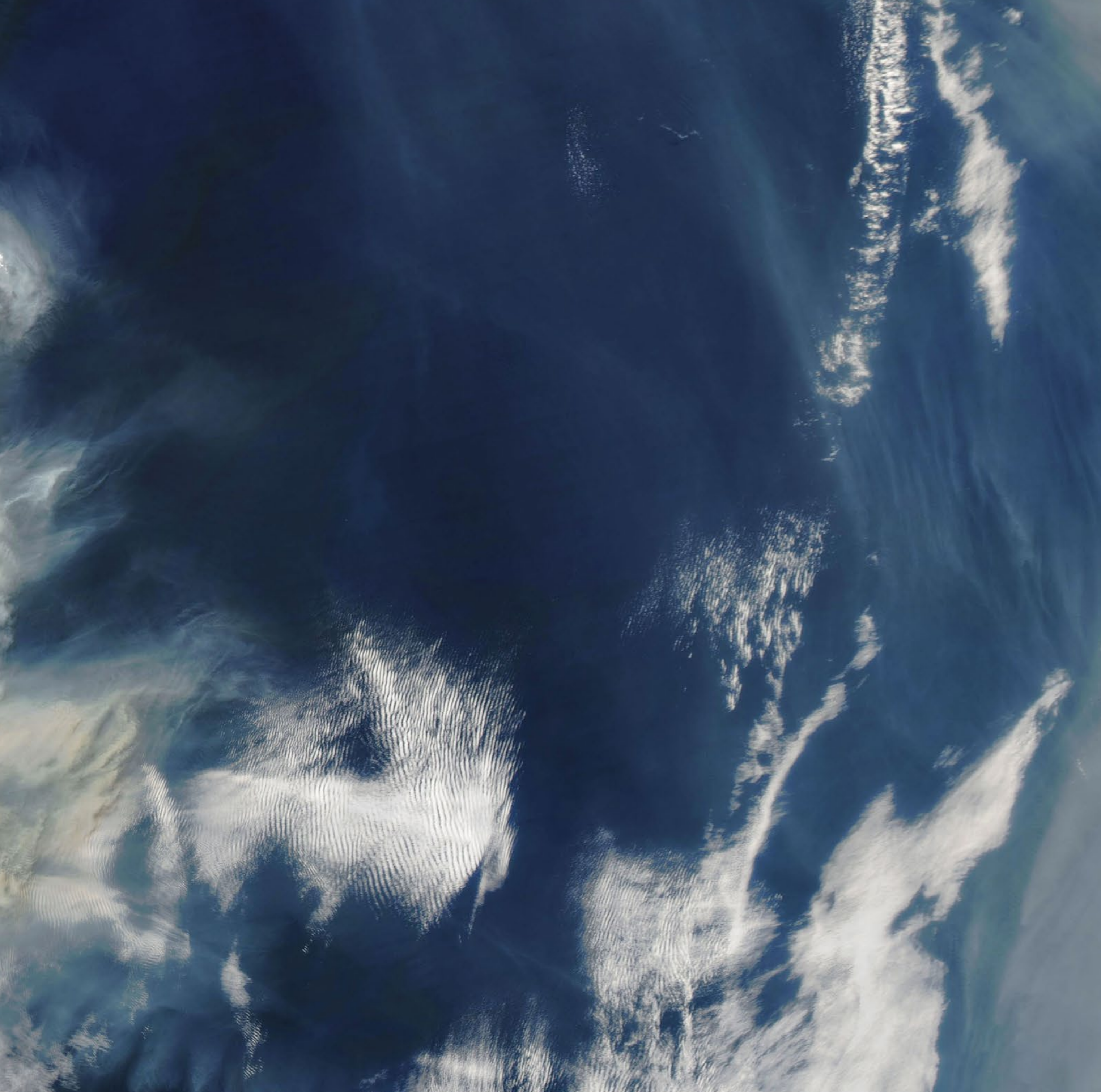
- Promote Transparency and Competition: Foster a competitive marketplace for RPAS services, driving innovation and ensuring cost-effectiveness for fire agencies.
- Coordinate Expertise: Provide a single point of contact for fire agencies to coordinate their procurement expertise. Enabling them to engage with, and task, accredited RPAS suppliers. This network of experienced procurement and RPAS tech experts would streamline the procurement process and increase administrative efficiency.
- Ensure Quality and Standards: Establish clear accreditation standards for RPAS suppliers, ensuring that services meet specific operational requirements, safety standards, and data management protocols.



Conclusion: A Shared Vision for a Safer Australia

The integration of RPAS technology presents a transformative opportunity to enhance Australia's bushfire management capabilities significantly. By embracing innovation, fostering collaboration between stakeholders, addressing existing barriers, and investing strategically in research and development, Australia can harness the power of RPAS to protect communities, safeguard our environment, and build a more resilient nation in the face of escalating bushfire threats.

This roadmap provides a pathway forward, outlining a shared vision for a safer Australia where cutting-edge aviation technologies play a vital role in mitigating the devastating impacts of bushfires. The time for action is now. By working together, we can turn this vision into reality.



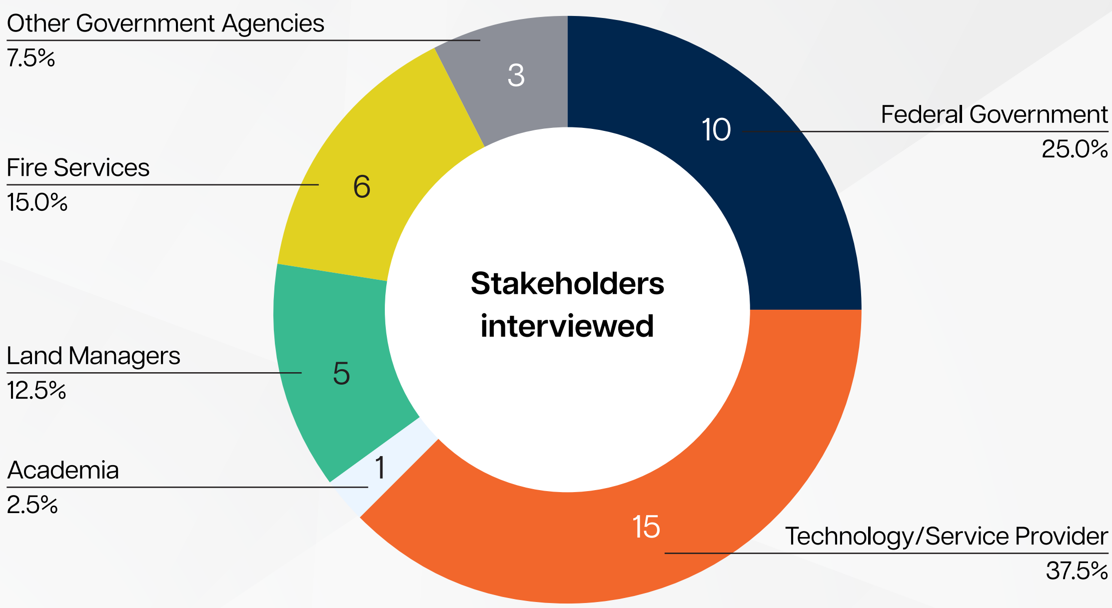
Glossary

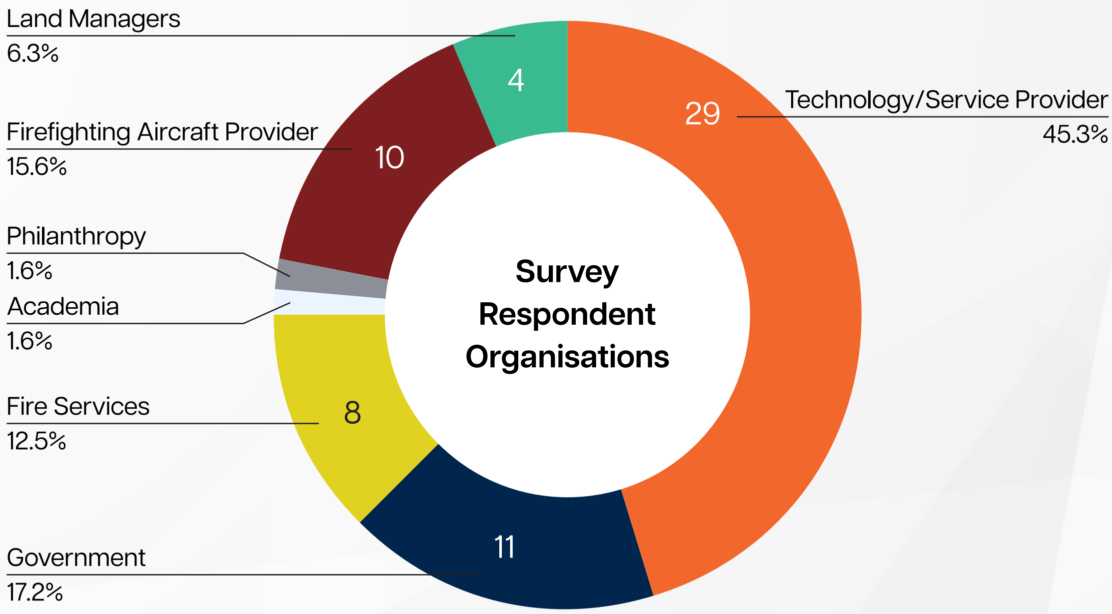
AAUS	Australian Association for Uncrewed Systems
ACERO	Advanced Capabilities for Emergency Response Operations (NASA project)
ADS-B	Automatic Dependent Surveillance–Broadcast aircraft location service
AFAC	Australasian Fire and Emergency Service Authorities Council
AGL	Above ground level
Airworthiness	The ability of an aircraft to perform operations safely and reliably in all expected conditions
ALFUS	Autonomy Levels For Unmanned Systems
ATM	Air traffic management. A system that ensures the safe and efficient movement of aircraft through the airspace.
Avionics	Electronic systems and equipment specifically designed for use in aviation
Back burn	A fire lit close to the edge of an active bushfire, which burns out the fuel between the bushfire and an established control line.
BLM	Bureau of Land Management, USA
BRCoE	Bushfire Research Centre of Excellence, The Australian National University
Burnt area	The total land area that has been damaged or destroyed by a bushfire
BVLOS	Beyond Visual Line of Sight
CAL FIRE	California Department of Forestry and Fire Protection, USA
CASA	Civil Aviation Safety Authority
Class G airspace	Portion of the airspace that is not controlled by air traffic management in Australia
Climb	The process of increasing the altitude of an aerial vehicle
COMDISPLAN	Commonwealth Disaster Response Plan
Controlled burn	Bushfire set intentionally to reduce fuel loads.
COTS	Commercial Off The Shelf. Products that are readily available for purchase and can be used without significant customization
Cruise	Main phase of a flight starting after a climb
DAA	Detect And Avoid. An type of air traffic collision avoidance
Deconfliction	The process of ensuring that aircraft do not collide
DEECA	Department of Energy, Environment and Climate Action, Victoria
DFES	Department of Fire and Emergency Services, Western Australia
DITRDCA	The Department of Infrastructure, Transport, Regional Development, Communications and the Arts
Drone	An uncrewed aerial vehicle
EC	Electronic conspicuity. The ability of electronic devices to be easily seen or detected
Exteroceptive	The ability to perceive external stimulus from sensors such as camera and radars
FAA	Federal Aviation Administration, FAA
FATM	Fire Air Traffic Management

fire front	The leading edge of a wildfire, where the flames are most active and the heat is most intense
Fire tower	Elevated structure built in a strategic location for spotting and reporting bushfires
Fire bombing	The use of aerial resources to deliver retardants or suppressants onto bushfires
FirEUrisk	Project focused on developing a risk-wise strategy for wildfire management, EU
Fixed wing	An aerial vehicle which uses stationary wings to generate lift
Fuel load	Amount of flammable vegetation available to fuel fire
Geolocation	The process of identifying a geographic location
Gimbal system	mechanical device that allows a camera or other sensor to rotate freely in multiple axes
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
Hyperspectral	Information across a very wide spectrum of light, beyond the visible spectrum
Ignition detection	Early warning systems in proactive fire management strategies
Incendiary	Device for intentionally igniting a fire
infrared camera	Camera that captures images in the infrared spectrum of light
ISR	Intelligence Surveillance and Reconnaissance
Loiter	Capability of an aerial vehicle to remain over a specific location for an extended period
LEO	Low Earth Orbit. Satellite with an orbital period of less than 128 minutes.
Low level flight	Any flight below 500f AGL.
Multirotor	An aerial vehicle with more than one rotor
NAFC	National Aerial Firefighting Centre
NASA	National Aeronautics and Space Administration
NEMA	National Emergency Management Agency
NPWS	NSW National Parks and Wildlife Service
NSW	The state of New South Wales
Payload	The objects or sensors carried by a aerial vehicle
Powered lift vehicle	Fixed wing aerial vehicle that can takes off and land vertically.
Prescribed burn	Bushfire set intentionally to reduce fuel loads.
QFD	Queensland Fire Department
QLD	The state of Queensland
Quadrotor	An aerial vehicle with four rotors
RAFT	Remote Area Fire Teams
Remote pilot	The person operating an uncrewed aerial vehicle from a ground station
remote sensing	The acquisition of information about the Earth's surface and atmosphere from a distance
Retardant	Substance that slows down or stops the progress of fire
RGB camera	Camera that captures images covering the red, green and blue spectra of visible light
RPA	Remotely Piloted Aircraft

RPAS	Remotely Piloted Aircraft System
Sensors	Devices that detect changes in their environment
Servo	type of motor system used for precise control of movement
SES	State Emergency Service
Sky cranes	Specialised type of helicopter designed to lift and transport heavy loads
Spatial data	Data that has a geographical or locational component
Spatial uncertainty	The inherent imprecision or error associated with the determination of a location.
Stack	Holding pattern for aircraft with vertical separation
Streaming	Multimedia delivered over a network
Suppressant	Substance or system designed to extinguish or control fire
Tail sitter	A type of VTOL aircraft that takes off and lands on its tail, then tilts horizontally for forward flight.
temporal resolution	The smallest unit of a measurement with respect to time
Terrain mapping	The process of creating detailed representations of the Earth's surface
Tilt rotor	Rotors that tilt from vertical to horizontal for use in both VTOL and cruise flight
TRL	Technology Readiness Level. Scale used to assess the maturity of a particular technology
UAFA	United Aerial Firefighters Association, USA
VIC	The state of Victoria
VTOL	Vertical Take Off and Landing
Water bombing	The use of aerial resources to deliver water onto bushfires
Waypoint	Reference point along a route for navigation

Annex A: Stakeholders Engaged





Interviewed Organisations	
Organisation Title	**Organisation Category**
Natural Hazards Research Australia	Academia
Civil Aviation Safety Authority (CASA)	Federal Gov't
Australasian Fire and Emergency Service Authorities Council (AFAC)	Federal Gov't
Department of Infrastructure, Transport, Regional Development, Communications and the Arts	Federal Gov't
Invest Victoria	Federal Gov't
National Aerial Firefighting Centre	Federal Gov't
NSW Office of the Chief Scientist and Engineer	Federal Gov't
Queensland Fire Department (formerly Queensland Fire and Emergency Service)	Fire Services
Queensland Police Service (formerly State Emergency Service)	Fire Services
Department of Fire and Emergency Services	Fire Services
Fire Rescue Victoria	Fire Services
United Aerial Firefighters Association	Firefighting Aircraft Providers
Department of Biodiversity, Conservation and Attractions	Land Managers
Victorian Department of Energy, Environment and Climate Action	Land Managers
Bushfire NT	Land Managers
NSW National Parks and Wildlife Service	Land Managers
Office of the NSW Chief Scientist & Engineer	Other Government Agency
National Interagency Fire Center	Other Government Agency
Revolution Aerospace	Technology/Service Provider
Big Drone	Technology/Service Provider
Taz Drone Solutions	Technology/Service Provider
Innovation Pro	Technology/Service Provider
Remote Aerospace	Technology/Service Provider
Australian Association for Uncrewed Systems	Technology/Service Provider
Skyfarer	Technology/Service Provider
Carbonix	Technology/Service Provider
National Drones	Technology/Service Provider
Hover UAV	Technology/Service Provider
Fi Sci	Technology/Service Provider
ArgenTech Solutions	Technology/Service Provider

Survey Respondent Organisations	
Organisation Title	**Organisation Category**
FPInnovations	Academia
Queensland Fire Department	Fire Services
Anonymous	Fire Services
Anonymous	Fire Services
Fire Rescue Victoria	Fire Services
NSW Rural Fire Service	Fire Services
Shire of Carnarvon	Fire Services
Department of Justice.	Fire Services
Fire Rescue Victoria	Fire Services
Airspace Experience Technologies	Firefighting Aircraft Provider
Solaris Suborbital	Firefighting Aircraft Provider
AGAIR	Firefighting Aircraft Provider
AGAIR	Firefighting Aircraft Provider
Ninox Robotics	Firefighting Aircraft Provider
AGAIR	Firefighting Aircraft Provider
Overwatch Aero, LLC	Firefighting Aircraft Provider
Collective Strategies & Communications	Firefighting Aircraft Provider
Fire Neural Network	Firefighting Aircraft Provider
Bridger Aerospace	Firefighting Aircraft Provider
Department for Environment and Water	Government
AFAC	Government
Department of Energy, Environment & Climate Action (DEECA)	Government
Department of Fire and Emergency Services	Government
U.S. Dept. of Homeland Security	Government
DFES	Government
Tasmania Fire Service	Government
Department of Energy, Environment and Climate Action (DEECA)	Government
Shire of Donnybrook Balingup	Government
City of Greater Geraldton	Government
Shire of Murray	Government
Taz Drone Solutions	Land Manager
Anonymous	Land Manager
Anonymous	Land Manager
City of Busselton	Land Manager

Organisation Title	Organisation Category
Anonymous	Philanthropy
Indicium Dynamics	Technology/Service Provider
Controlled Burning Contractors	Technology/Service Provider
Anonymous	Technology/Service Provider
Fi-Sci	Technology/Service Provider
Surf Life Saving Services Pty Ltd.	Technology/Service Provider
BurnBot Inc	Technology/Service Provider
FireSwarm Solutions	Technology/Service Provider
Iotdata.io	Technology/Service Provider
AFAC	Technology/Service Provider
Taz Drone Solutions	Technology/Service Provider
Anonymous	Technology/Service Provider
Vector robotics	Technology/Service Provider
Overwatch Aero, LLC	Technology/Service Provider
Fireline Solutions	Technology/Service Provider
Hover UAV	Technology/Service Provider
Ciconia	Technology/Service Provider
Dufour Aerospace	Technology/Service Provider
Sceye Inc	Technology/Service Provider
Aloft	Technology/Service Provider
ANRA Technologies, Inc	Technology/Service Provider
Solaris Suborbital	Technology/Service Provider
Komodo-Fire.com	Technology/Service Provider
Parallel Flight Technologies	Technology/Service Provider
Nippon Kayaku Company (Parent); Aero Systems West (UAS)	Technology/Service Provider
Rain	Technology/Service Provider
Carbonix	Technology/Service Provider
Mitsubishi Electric US	Technology/Service Provider
GreenSight	Technology/Service Provider
Raindance Systems Pty Ltd	Technology/Service Provider

Photos

Gary Hooker, AFSM, ACT Rural Fire Service

Front Cover Fire heading into rugged terrain near the ignition point of the Orroral Valley Fire, located in the Namadgi National Park, ACT (Note: DJI drone image added to original photo)

p. vi, vii Silhouette of firefighters watching in awe at the Orroral Valley fire on its first night, located in the Namadgi National Park, ACT.

p. 8 A DC10 air tanker delivers retardant during the 2020 Black Summer bushfires, directly behind the Tharwa General Store, ACT.

p. 10 Image of DJI Mavic 2 Enterprise drone

p. 16 (insert), p. 40 ANU BRCoE Researchers using an Arace Angle at a recent hazard reduction burn, located at Bullen Range, ACT

p. 21 Backburning near Gibraltar Falls, ACT

p. 25 Back-burning near Snowy Mountains Highway, Adaminaby, NSW

p. 29 Tree found well alight amongst loose leaf litter, near Adaminaby, NSW

p. 33 DC10 Large Air Tanker (LAT) based at Canberra Airport

p. 34 Water-bombing of hot spots near Braidwood, North Black Range Fire, NSW

p. 49 DJI M30T drone on display at the AFAC conference, held at the International Convention Centre, Sydney Sep 2024

p. 51 A new spot fire is started by a stray ember blown ahead of the main fire-front, located near the base of Mt Tennant, ACT

p. 66-67 A helicopter dips a water bucket into the Orroral River near the ignition point of the Orroral Valley Fire, Namadgi National Park, ACT

Kerry Buonopane

p. ii The Orroral Valley Fire is clearly visible near Canberra suburbs at night. View is from Dairy Farmers Hill, National Arboretum, ACT

p. 41 The Orroral Valley Fire approaching Point Hut Pond, Gordon, ACT at night

Brett Vey, ACT Rural Fire Service

p.50 Ember attack on Old Schoolhouse Museum, Nerriga, NSW (Note: The Museum was saved by NSW and ACT RFS crews)

Saidynamics

p.22 Bremer 80 multirotor RPAS for incendiary delivery during a controlled burn in Gibb River, WA.

Marta Yebra

p. 32 Charred remains of a tree captured during a helicopter campaign assessing the burn severity of the Orroral Valley fire.

p. 37 Scorched trees in the Orroral Valley, photographed during a helicopter campaign to assess the burn severity of the Orroral Valley fire.

Nic Vevers/ANU

p. 43 An Arace Angel quad-copter fitted with an IR camera on display at the ANU's Bushfire Research Center of Excellence Showcase 2024.

p. 44 ACT Parks and Conservation officer remote piloting an Arace Angel RPAS.

NASA

p. 14 & 30: Altair Photo Collection https://www.dfrc.nasa.gov/Gallery/Photo/Altair_PredatorB/index.html

p. 56: Fires and Smoke Engulf Southeastern Australia https://earthobservatory.nasa.gov/images/146110/fires-and-smoke-engulf-southeastern-australia

Unsplash

p. i Ian Usher (DJI drone insert)

p. vii Josué Soto (insert)

p. 46 Sam McGhee

Pixabay

p. 12 Thomas Ehrhardt

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