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UNITING THE GLOBAL WILDLAND FIRE COMMUNITY

WILDFIRE®

An official publication of the INTERNATIONAL ASSOCIATION OF WILDLAND FIRE

SPECIAL ISSUE:

THE EFFECTIVENESS OF AERIAL FIRE FIGHTING

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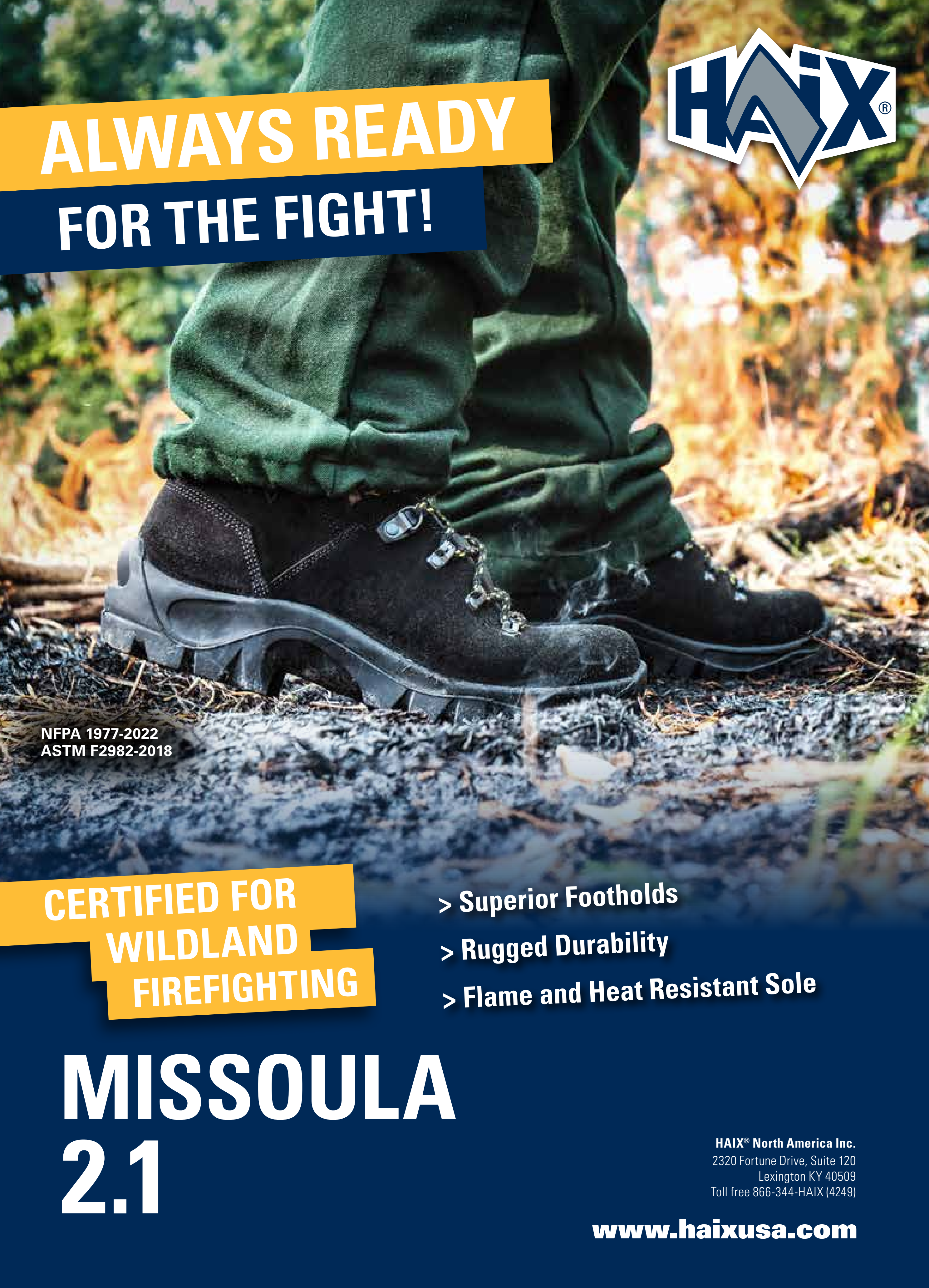
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OPINION

SPECIAL SECTION

AERIAL FIRE FIGHTING

ON THE COVER: A CL-415 tanker #259 from Manitoba dropping on a wildfire during a SOPFEU crew deployment in Alberta in 2023. On site, the firefighting crew was divided into several small initial attack teams (for responding to new fires), deployed to different regions of the province: Lac La Biche, Rocky Mountain House, Grande Prairie, Whitecourt, and others. Photo courtesy of ©SOPFEU- Jesse L, May 2023.

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UNDERSTANDING AERIAL FIRE FIGHTING

BY LAURA KING

When some Canadian colleagues approached *Wildfire* magazine about a special issue focusing on international aerial fire fighting, it was a no-brainer.

Australia, Canada, France (and other parts of Europe), and the United States are battling epic wildfires. The role of airtankers to help control unplanned wildland fires, save lives, and reduce loss is critical but also needs continuous study to determine effectiveness and best practices.

How effective are water and / or retardant drops? Do the risks outweigh the benefits? What are the optimum operating procedures? Who's doing what research? Who's using which planes or helicopters? Who's sharing information with whom?

In Canada, the 2023 wildfire season broke all the bad records, and 2025 started similarly. This season, planes and manpower came from the United States, Australia and other places. In January, Canadian airtankers – or waterbombers, as they're known – worked the devastating Los Angeles fires, and have, for decades, helped U.S. and other counterparts.

The team that collaborated on our cover story, Flights Over Flames (page 8), spans the globe. The combined research and operational experience of the 12 writers is remarkable and represents the key research and deployment agencies in Australia, Canada, France and the United States.

"While these aircraft can often play a critical role in combating fires," the team says, "like all frontline fire fighting, aerial suppression also carries significant risks . . .

"In some parts of the world, studies have shown a large proportion of firefighter fatalities were linked to aviation accidents . . ."

What does the research say?

In Australia (page 18), there is little data on the effectiveness of aircraft use for wildland fire control or suppression.

"Most of the existing operational understanding of suppression effectiveness is anecdotal, highly personal and difficult to compile," according to writers Matt Plucinski, Nick McCarthy and Deb Sparkes.

Even though a key project, called Why fly? How do we know that aerial firefighting operations are effective and efficient?, is happening in Australia, the work is unlikely to provide the necessary insight and is expected to recommend more research.

"Important issues, such as line productivity and holding, non-aircraft benefits, cost effectiveness, and the effectiveness of retardants and suppressant are not being investigated …" the writers say; they encourage better data collection and availability.

In Canada, suppression with airtankers is a core strategy for the country's 10 provinces and three territories (page 24). According to writers Melanie Wheatley, Colin McFayden, Razim Refai, Emily Hope and Heather Simpson, experiments are underway involving airtanker drops, deployment strategies, dispatch prioritization and understanding, and maximizing the effectiveness of airtanker use on fires.

Research in the United States has primarily targeted large airtankers, according to writers Dave Calkin, Cal Bryan and Jim Riddering (page 34).

"Studies have focused on understanding where and when aviation drops occur, how fire managers prioritize the use of aviation, optimal fleet design, and how risk management concepts can inform where and when to most effectively apply aviation."

France has been studying airdrops since 1995 (page 46), including ground-pattern efficiency, through research similar to the cup-and-grid system being used for research in Canada.

Our story form South Africa on page 40 explains the government's role in the Working on Fire Programme and privately owned and operated aerial firefighting resources.

"The introduction of aircraft to combat fires from above significantly improved response times, enabling quicker containment and minimising losses," says writer Trevor Abrahams.

"Aerial fire fighting not only saved the South African commercial forestry industry from collapse but became an integral part of the current wildfire management strategies that protect South Africa's natural environment."

As IAWF president Trevor Howard notes in his column on pages 6-7, Australia has embraced airtankers for prescribed or controlled burns and to detect wildfires.

"Taking an even broader view of aerial fire fighting, aerial ignition is an essential and well-proven approach to managing land and mitigating the effects and impacts of wildfires, as well as for backburning and burning out areas during wildfire suppression operations," Howard says.

The content in this special issue of *Wildfire*, developed by 18 researchers and aerial fire fighting experts, is insightful and thought provoking and will, hopefully, help ensure global collaboration to improve programs and safety.

Managing editor Laura King is an experienced international journalist who has spent more than 15 years writing and editing fire publications. She is the Canadian director for the National Fire Protection Association (NFPA), works closely with FireSmart™ Canada to help residents build resilience to wildland fire, and has participated in the development of the Canadian wildland fire prevention and mitigation strategy.

WIDENING THE LENS ON AERIAL FIRE FIGHTING

BY TREVOR HOWARD

This edition of *Wildfire* magazine covers the important, sometimes misunderstood, and often debated topic of aerial fire fighting. We have four articles by researchers from France, Canada, the United States, and Australia evaluating the effectiveness of aerial wildfire suppression. This work makes a significant contribution to our body of knowledge on aerial fire fighting and each of the studies has included some operational input, but there are many other viewpoints and perspectives on effectiveness in fire and aviation.

While the roles and titles differ across the globe, incident management teams normally set overall incident objectives, with the officer responsible for operations developing, implementing and adjusting strategies and tactics through divisions and sectors, intelligence from the field etc. A supervisor of aerial operations, in an aircraft above the incident, coordinates all other aircraft and also adjusts strategies and tactics according to conditions, the effectiveness of water, foam, and retardant drops, personal observations, and communication with a ground controller. So, there are various players in the operational chain of command, including pilots, who are experts in the effectiveness of aerial fire fighting and stakeholders in this discussion. We'd like to hear more from them in future issues of Wildfire.

It is also important to highlight the broader context of aerial fire fighting. While usually under contracts and operational control by government agencies, there are many unseen parts of aerial fire fighting. For a start, the private sector makes a massive investment in aircraft, infrastructure and technology as well as employment in a vast range of roles to deliver and maintain aircraft and services. The links between fire agencies and aviation companies are often quite different than other contracted operational services, such as earthmoving machinery. With aviators and their support teams operating from airfields and hangars, pilots communicating with agency air attack supervisors above incidents, and other specialists dealing with seasonal preparedness, contractual matters and after-action reviews, some opportunities to collaborate and learn from each other may not be realised. For example, wildland fire agencies have long been held up by researchers as high reliability organisations, performing consistently and safely in hazardous operating environments, while aviation companies have their own expertise, cultures, procedures and communications protocols to ensure reliability, risk and safety management, and resilience.

Another largely unseen aspect of aerial fire fighting also happens well away from firegrounds and the public. In Australia, fixed-wing aircraft, especially the smaller single engine air tankers, often work from rural airfields where the local community steps up to support operations. Many of the people with roles in reloading aircraft with water and additives for effectiveness, come from local volunteer fire brigades, emergency services units and the like. Sometimes low-risk prisoners from regional correctional services facilities are actively involved. Aerial fire fighting doesn't just protect rural communities, it involves them in ways that can be mutually beneficial and long-lasting.

Aerial fire fighting is not just about dropping suppressants on fires and retardants on vegetation. Surveillance and reconnaissance flights involving a broad range of aircraft types and technologies are essential for capturing the location, extent, intensity and potential impacts of fires and for translating that intelligence into a common operating picture and strategies for action. Suitably equipped aircraft can capture and share images and data during night-time operations and when smoke and cloud hinder other flights and visual assessments. These applications are not just for managing wildfires. Western Australia, for example, has one the largest science-based prescribed burning programs in the world, and for more than 50 years has used a fleet of small aircraft (currently the American Champion Scout) to monitor active prescribed burns as well as to detect wildfires. Multiple daily flights and circuits are planned and scheduled according to active burn and current wildfire locations, fire danger indices, areas of high risk (campgrounds, for example), and visibility from a network of fire towers across forested lands.

Taking an even broader view of aerial fire fighting, aerial ignition is an essential and well-proven approach to managing land and mitigating the effects and impacts of wildfires, as well as for backburning and burning out areas during wildfire suppression operations. Developed in Australia and pioneered operationally in the southwest forests in the mid-1960s, aerial ignition is now used around the world. Its usefulness and potential are yet to be fully realised in parts of the world that are experiencing major changes in climate and fire regimes, such as northern Europe. In Australia today, beyond the management of fuels in forestry, parks and conservation, pastoralism, and rural fire management contexts, it is in the north of the country that the major users of aerial ignition are Indigenous organisations, burning for cultural, biodiversity and carbon outcomes. As drones and other technologies advance, lower cost, locally led programs and operations will be enabled. With IAWF members in 36 countries with different government agencies, resources, geographies, cultures, communities and land uses, this context and perspective on aerial fire fighting takes us beyond developed and developing nations.

Trevor Howard is the national manager, prescribed burning strategy, with the Australasian Fire and Emergency Service Authorities Council (AFAC). Based at the Bushfire Centre of Excellence in Western Australia, Howard leads national capability developmentfor prescribed burning and supports rural fire services, land management agencies and non-government organisations with continual improvement.

FLIGHTS OVER FLAMES

EXPLORING THE SCIENCE OF AERIAL SUPPRESSION

BY COLIN MCFAYDEN, DAVID CALKIN, FRÉDÉRIQUE GIROUD, EMILY HOPE, RANA KAMH, DOMINIQUE LEGENDRE, NICK MCCARTHY, MATT PLUCINSKI, OWEN PRICE, MELANIE WHEATLEY, RAZIM REFAI, AND HEATHER SIMPSON

Wildfire management is complex and uncertain, and it can be hazardous, particularly when fires escape the initial attack and grow large.

Fire managers regularly make decisions about what actions to take, when and where, all while considering available suppression resources working in time-sensitive and critical environments.

Aviation resources have become an iconic symbol of wildfire suppression. When wildfire response is depicted in the media, we often see images of aircraft battling the fire. Aircraft help ground resources, and they can be instrumental in many situations, such as facilitating a rapid initial attack, and helping ground crews gain the upper hand in tough conditions, but they are also one of the most expensive resources. What do we know about the effectiveness of aircraft?

What is aerial suppression? We are lumping airtankers (fixed-wing aircraft) together with helicopters to include all aircraft capable of dropping water, chemical suppressant or retardant on to wildfires from a tank or bucket system.

Those who regularly fly and work with the airtankers see how they function in real time and a considerable pool of expertise has been developed over the years. The research challenge is to better understand how aerial suppression helps fire managers meet objectives and how aerial suppression contributes to or aligns with broader societal objectives of fire management.

WILDFIRES

Fire is essential in many ecosystems and important to people and cultures worldwide but can also have devastating consequences for people, communities, the economy and the environment. In the last five years alone there have been multiple protracted and damaging wildfire events such as Australia's Black Summer in 2019-2020, the record-breaking 2023 Canadian fire season, large or widespread fires in eastern Russia, and consistently challenging fire seasons for South America with 2024 standing out as particularly severe for Chile and the Amazon. There also have been severely impactful wildfires in the United States (Texas, New Mexico, Colorado, Hawaii, and California), and Europe and Asia have not been immune.

Many of the most devastating and publicized and high-fatality events have occurred under extreme fire weather conditions (blow-up fires such as Black Saturday, Australia 2009, Portugal 2017, Greece 2018, Hawaii 2023, and California). On these extreme fire weather days, when there are high winds, turbulence, smoke, and low visibility, it can be too dangerous for aircraft to fly, let alone be effective in low-to-ground suppression action.

The safe operation of aircraft is typically limited to maximum wind speeds of 20-25 knots (37-46 km/hr or 23-29 mph) for crosswinds with gust limits of 30-40 knots (56-74 km/hr or 35-46 mph) depending on the type of aircraft. Rotary-wing or larger aircraft can tolerate higher wind speeds, but their maneuverability decreases under such conditions, making precision tasks like suppression drops more challenging. In extreme fire weather conditions, the fire may be too hot or intense to be slowed or be halted by aerial suppression. Soley increasing the number of aircraft is not the silver bullet to these challenging days.

Research has warned us that across the globe, wildfires are increasing in frequency and severity, driven by the effects of climate change and the legacy of a century of wildfire suppression. Simultaneously, the encroachment of buildings and infrastructure into wildland areas are putting more assets and people at risk. In response, the people and organizations that manage wildfire seek to address these mounting challenges through some degree and combination of fire management levers including prevention, mitigation, community engagement and suppression strategies.

The way countries manage wildfires is as diverse as their landscapes, people and cultures. While the specific methods used around the globe differ to the local needs and contexts, there are some shared approaches and tools in the toolbox, such as using aircraft to support suppression efforts. One question across all these countries is how hard we should and can pull on the suppression 'lever' of aircraft, noting it is not without risk.

By finding and recognizing the limit of the aerial suppression lever, we can look at using aircraft to keep fire risk "as low as reasonably practical" without incurring disproportionate costs. Importantly, this cost is more than financial; it includes real safety risk to our people and trade-offs with other management levers. This concept is shown in figure 1 (page 11), where there

The Quebec #237 CL 215 photographed at the Service Aérien Gouvernemental headquarters in Quebec City on May 5, 2022. Photo by Audrey Marcoux. Photo courtesy of Service Aérien Gouvernemental Headquarters ©SOPFEU-Audrey M. May 2022.

is a point at which the level of risk cannot be further reduced without disproportionate costs or risk to aircrew and firefighters relative to the benefit gained. Beyond this point, doing more and spending more puts people in potentially dangerous situations with little extra benefit.

THE ROLE OF TACTICAL AIRCRAFT IN WILDFIRE SUPPRESSION

While aircraft aren't needed or used to suppress all wildfires, they are often deployed to fires that have the potential to threaten lives and property, as well as to fires that are inaccessible to ground crews or to aid ground crews by cooling or slowing a fire to allow the ground crews to be more effective. Remember, it's the ground crews who extinguish the fire. Aerial suppression can support both initial attack and sustained action efforts, providing rapid initial response to new fires and prolonged suppression support on larger fires.

How these aircraft are deployed and used to fight wildfires varies based on their type and capabilities: some drop suppressant directly on flames to slow fire spread, while others release retardant chemicals ahead of the fire to alter its course and protect critical areas. There is also extensive use of aircraft for intelligence, coordination and monitoring of crew movement and logistics functions, but we are focusing on the tactical aircraft that conduct the drops. These tactical aircraft come in a range of sizes and configurations, often differentiated by drop capacity, filling methods and delivery mechanisms. Wildfire management organizations operate with fleets often composed of multiple different types of aircraft to address the challenges of operating in a variety of environments, different levels of fire behaviour, and varying suppression objectives. From helicopters with buckets delivering 300 to 400 liters (80 to 105 gallons) to supertankers releasing a staggering 45,000 liters (11,887 gallons).

While these aircraft can often play a critical role in combating fires, like all frontline fire fighting, aerial suppression also carries significant risks, and the use and misuse can lead to dangerous situations for aircrew

Airtanker 417 dropping along a fire flank in the Northwest Territories. Photo courtesy of the Government of the Northwest Territories.

and firefighters alike. In some parts of the world, studies have shown a large proportion of firefighter fatalities were linked to aviation accidents, underscoring the inherent dangers of aerial firefighting and the need for safety-first approaches.

Wildfire management organizations that operate aerial suppression fleets devote large portions of their operating budgets towards them. Airtankers are expensive to purchase, contract, maintain and operate, and the costs associated with their use are increasing.

Wildfire management organizations often do not have the financial resources, or personnel to operate enough aircraft to address every fire that could benefit from aircraft action. One clear but thankfully rare example of this is in a mass lightning ignition event, where dozens to hundreds of fires can ignite in a single day. In these situations, it's not feasible for any organization to maintain enough resources for the extreme peak but infrequent demand. Recent examples include November 2019 during the Black Summer season in southeast Australia and August 2020 in California. In both instances, the lightning fires burned more than 1 million hectares.

It's also not the case that having more aircraft means every fire will be extinguished. There are instances where it's just too dry and too windy to stop a fire in its tracks, and even when aircraft are effective, they often provide the initial hit to then allow ground-based firefighters to make access and do the hard work of truly extinguishing the fire.

However, when there are shortages of aircraft, some organizations augment their fleets by borrowing from other jurisdictions (nationally and internationally) and using resource sharing agreements and contracts. Airtankers are highly mobile and can easily move between low- and high-risk areas and be shared across jurisdictional borders. This too is not without expense and trade-offs, as with all scarce resources.

Of course, the cost of operating aerial suppression pales to the potential impact posed by some of the most destructive fires. We've listed numerous examples of high-cost and damage wildfires, some with damage estimates in the billions of dollars, many with even higher costs in less direct impacts such as public health. Could changes in aircraft usage have prevented some of these damaging fires? Or were the damages inevitable given the extreme fire weather conditions? Decision makers must decide how to use their limited number of aircraft resources to prevent fires from escaping containment efforts and reduce the potential negative impacts of the fires that do escape.

Allocating airtankers to appropriate fires where they can be most 'effective' and safe is the best outcome, but these decisions rely on tactical experience that is difficult to quantify and share, and assumptions about the effectiveness of aerial suppression.

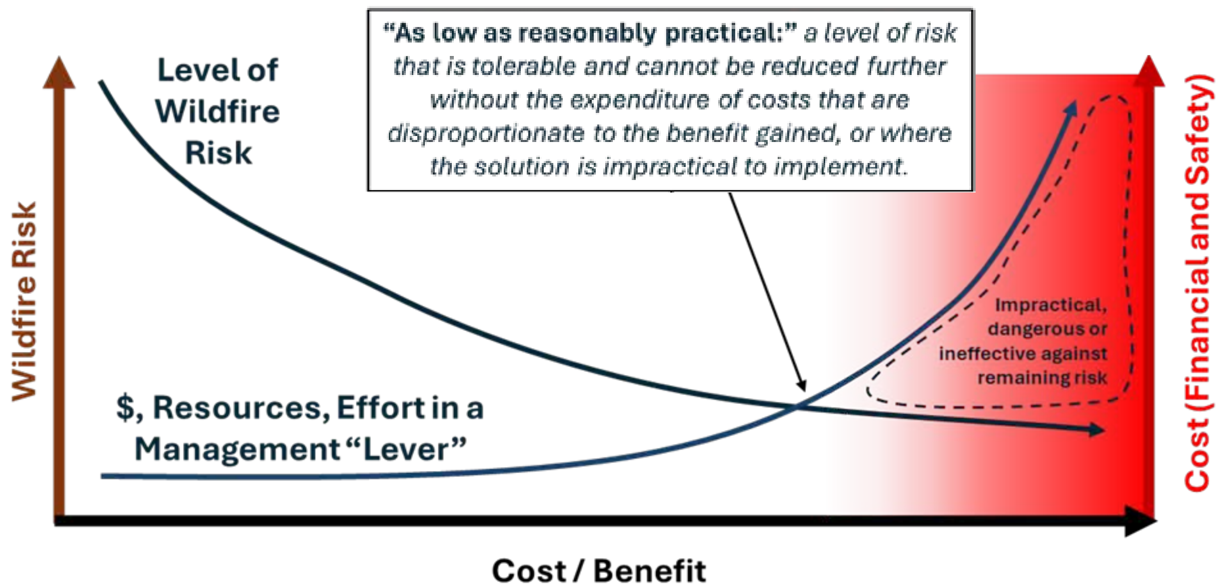


Figure 1: The concept of as low as reasonably practical.

To the experienced wildfire tactician, aircraft can be a welcome tool for crew safety, fire intelligence, and to stop a fire from escaping initial attack and becoming one of those stories of devastation. Allocation decisions are not straightforward, and there are influences (e.g., the incentives for decision-makers and cultural factors) that affect the deployment and use of aircraft. This often leaves us with questions like "Is the appropriate level of aircraft use consistent with the objectives of the fire relative to what's achievable and what is safe to do?". A 2021 study suggested the risk management protocols of aviation and fire management may not be appropriately scaled in terms of how the tactical use of aircraft aligns with the incident strategy and broader societal goals of fire management. For large fire incident management, this can translate to a culture of "get them if you can and use them if you've got them."

There have been several recent efforts to better understand aerial suppression use in wildfire management from a scientific and economic perspective, such as the Aerial Firefighting Use and Effectiveness study in the United States, the LABEX (Largage Bombardier d'Eau EXpérimentation) experiments in France and the aptly named Australian Why fly? project.

The continued use of aerial suppression across the decades by those on the frontlines speaks to their role as one of the more versatile and rapidly deployable suppression tools in the toolbox. However, compared to the extensive research on how fires ignite and spread far less attention has been given to studying the effectiveness of aircraft fighting fire despite their iconic presence, widespread use, and growing demand.

AERIAL SUPPRESSION EFFECTIVENESS AS A RESEARCH AND OPERATIONAL CHALLENGE

Quantifying aerial suppression effectiveness can lead to improved firefighting strategies, optimal use of suppression resources, and more informed strategic investments by fire management agencies. If we know more, we can do more safely and invest appropriately. This is especially pressing given the high costs, limited availability of airtankers, and the mounting challenges of a changing climate to manage more fire, more often, in more areas.

So, what does effectiveness mean with aircraft? It comes down to the objective you are trying to achieve. To the firefighter, it might mean how reliably they can prevent a fire from crossing a control line, and the multiplier effect having an aircraft can have. A dispatcher may assess effectiveness in terms of efficiency, for example, by how quickly an aircraft responds to a fire. An organization administrator may judge effectiveness by the costs and benefits. To the aircrew, it could mean achieving any number of things relative to what's happening on the ground in a rapidly changing and dynamic situation. Because the notion of effectiveness means different things depending on the objectives, it's far from straightforward to describe and more complicated to research. One of the key research challenges is just trying to identify the objectives.

MEASURING EFFECTIVENESS

Understanding the different aspects of 'effectiveness' starts with asking questions like: What happens to the drop once it leaves the aircraft? How much of it gets its target (flames or fuel)? What happens to the fire when a suppression action is taken with an aircraft? Does it reduce intensity, slow or alter spread rates, or provide critical time for other firefighting resources to intervene, and if so, by how much, how long, at what cost and risk?

Some studies have shown aerial suppression increases the chances of successfully halting a fire when used during the initial attack of new fires. However, we do not have a strong quantitative understanding of how much liquid makes it through the canopy to targeted fuels, how long the impacts of water or retardants last, or at what point the efforts made by aircraft are no longer making a meaningful difference. This fundamental understanding of aircraft effectiveness would provide the basic building blocks needed to start answering many aspects of effectiveness that support the questions stated above.

Collecting the data needed to research these questions is difficult given the characteristics of dropping mechanisms and the dynamic nature of wildfire, yet valuable for ongoing learning, improvements, and guide investments. Beyond the challenges in studying fire behaviour, incorporating the suppression component creates added complexities. Environmental factors like wind, topography, fuel type and structure significantly influence how the fire will behave and how the fire responds to aerial suppression. Aircraft characteristics (e.g., speed, maneuverability, drop patterns, etc) and pilot skills will also influence outcomes. Dropping water or retardant is not as simple as letting gravity do the work. For example, how water leaves an aircraft is not the same for each type of airtanker. There are losses due to evaporation, wind drift and heat from the fire, and depending on the aircraft, its speed, altitude and coverage level, its load can come down as a light mist that gets caught up in a forest canopy or a thunderous force, breaking off tree tops off on the way to the ground. All of this is compounded by the interactions with the effectiveness of ground-based suppression activities where aerial suppression drops can knock down flames so that firefighters can finish extinguishing them. Without the drop firefighters may not have safe access; without the firefighters, flames will soon rebuild and spread as if the drop never happened.

These complexities make it challenging to gather the data needed to quantify, assess and model aerial suppression performance with scientific rigour. Moreover, data on fire and aviation that is recorded and archived by fire management organizations can be hard to access and infer conclusions due to complexities in aircraft use and underlying decision-making. A common example is images of retardant where fire has stopped implying effectiveness, but the absence of data may prevent observers from knowing if the fire stopped before retardant was applied. In most cases the actual decisions are not documented in a way or with sufficient context or accessibility for evaluation. This lack of documentation, available data and empirical understanding leaves many questions unanswered.

ADDRESSING THE GLOBAL CHALLENGE

Wildfires are a shared challenge that are expected to become more complex and difficult to manage in the future. We seek ways to keep potentially destructive wildfires small and communities safe when possible. Building our scientific knowledge on aerial suppression effectiveness and how to best use these aircraft is a way researchers can support the development of suppression strategies and long-term policy decisions around the configuration of firefighting aircraft fleets. Collaboration among researchers, fire managers, and policymakers is essential to obtaining this robust evidence-based knowledge. This includes building and communicating the evidence around the effectiveness and limits of aircraft, especially considering the

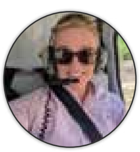

A CL-415 airtanker #246 drops on the 5.6-hectare fire 414-Chemin Arago in the southeastern part of the province of Quebec. This was a lightning-caused fire very late in the 2022 season. Photo by Audrey Marcoux. ©SOPFEU. Audrey M., May 2022.

mounting expectation of the public who expect to see aircraft when a fire starts. By addressing gaps in research and exploring innovative ways to evaluate airtanker effectiveness, the research community can help fire managers deal with wildfires more effectively.

Colin McFayden was born and raised in Northwestern Ontario and has spent 30 years working in fire management. Starting in the mid 1990s on a FireRanger crew, McFayden spent most of his career working for the Province of Ontario in roles from coordinating aerial fire detection to leading the wildland fire science program. In 2022, McFayden joined the federal Canadian Forest Service as part of the WildFireSat mission leadership team. McFayden co-authored the Reference Guide to the Drop Effectiveness of Skimmer and Rotary Wing Airtankers, published in 2023 by Natural Resources Canada.

Dave Calkin is a supervisory research forester with the US Forest Service, Rocky Mountain Research Station in Missoula, Montanna. Calkin's work is designed to improve risk-informed decision making through innovative science development, application, and delivery incorporating economics with risk and decision sciences. Calkin's research interests include risk assessment, collaborative wildfire mitigation and response planning, suppression effectiveness, and risk informed decision making. Calkin developed and leads the Wildfire Risk Management Science (WRMS) team within the US Forest Service Rocky Mountain Research Station.

Frédérique Giroud is the director of CEREN, the testing and experimentation Center of ENTENTE Valabre. She holds a PhD in fluid mechanics and heat transfer. She collaborates with scientists, firefighters and crisis managers to conduct various projects at the national and European level. Her main areas of research related to forest fires are fluid mechanics, fire spread modelling, chemical additives, wildland-urban interface management and fire instrumentation. Giroud is in charge of establishing contacts between French scientists and European stakeholders in the firefighting domain. Since 2018, Giroud has managed the reference laboratory for the French standardization of firefighter equipment. Since 2021, CEREN has been the approved inspection laboratory of French Civil Protection in the chemical additives area.



Emily Hope is a PhD candidate at the University of Toronto, studying the economics of wildland fire aviation. Hope's research will focus on key cost components associated with aerial suppression and explore how those costs might change into the future; her analyses will examine several issues, including optimal contracts, various aircraft ownership structures, labour and mechanic shortages, and maintenance scheduling.

Rana Kamh is a senior communications advisor at Natural Resources Canada. She supports communications for the department's emergency preparedness files, which include wildfires. Kamh has an MA in global development studies from Queen's University.

Dominique Legendre is a professor at Toulouse INP and the Institut de Mécanique des fluides de Toulouse (IMFT). He received his PhD in Fluid Mechanics at IMFT–Toulouse INP in 1996. He is president of the governing board of the International Conference on Multiphase Flows (ICMF). His work focuses on dispersed multiphase flows, and he has developed research investigation on the drop efficiency of airtankers by conducting both experiments in wind tunnel and numerical simulation.

Nick McCarthy is a senior research and development officer with Country Fire Authority's Research and Development team in Victoria, Australia, focusing on suppression effectiveness, future firefighting trends, and field data collection on fire behaviour. McCarthy previously worked as a postdoc with the U.S. Forest Service in Missoula, Montana, and completed a PhD at the University of Queensland in fire-atmosphere interactions.

Matt Plucinski is a senior research scientist at CSIRO in Canberra and has more than 20 years bushfire research and firefighting experience. Plucinski has conducted many field and laboratory experiments on topics associated with bushfire behaviour and suppression effectiveness, including evaluations of the effectiveness of large airtankers and assessments of wildfire suppressants and retardants. Plucinski's research has been used to inform risk management planning, response strategies during bushfires and for fire danger assessment.

Owen Price is director of the Centre for Environmental Risk Management of Bushfire at the University of Wollongong and for 18 years has been researching the evidence of impacts of bushfires on biodiversity and buildings and the effectiveness of strategies to reduce bushfire risk; this includes research on prescribed burning, construction standards and suppression with techniques involving spatial,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statistical modelling and simulation. Price was born in the United Kingdom and graduated as a biologist before moving to the Northern Territory in 1992, where he worked for 13 years in wildlife research for the National Parks and Wildlife Service. He has authored 140 papers and 50 reports and in 2020 he was joint winner of the Eureka Prize for applied environmental science for analysis supporting the NSW inquiry into the 2019-2020 Black Summer inquiry.

Razim Refai is a senior researcher with the wildfire operations research group at FPInnovations. His research focuses on aviation suppression efficacy and wildfire chemical effectiveness. Rafai also works with wildfire management agencies in Canada on program reviews to forecast provincial and territorial aviation resource needs.

Melanie Wheatley, PhD, is a wildland fire research scientist with the Ontario Ministry of Natural Resources, Aviation Forest Fire and Emergency Services. Her research focuses on applied fire management problems to support operational fire management decision making, including the development of situational awareness and decision support tools. Wheatley also specializes in aerial suppression effectiveness research, using a combination of data-driven methods and field observations to examine the effectiveness of waterbomber aircraft in the boreal forest. Wheatley has more than a decade of experience with the fire management program in Ontario, in working in various fire response and research related capacities.

Heather Simpson, a project manager at the Canadian Interagency Forest Fire Centre (CIFFC), brings a unique blend of frontline firefighting experience and academic expertise in wildfire management. With a decade of experience as a seasonal firefighter with the BC Wildfire Service, Simpson has firsthand knowledge of the complexities of wildfire suppression. She further honed her expertise by pursuing a PhD in fire management in Australia, where her research focused on improving fire line operations and developing advanced strategies for effective wildfire management. At CIFFC, Simpson leverages her extensive background in operations, liaison, and administration roles to inform policy, guide decision making, and drive innovation in wildfire management.

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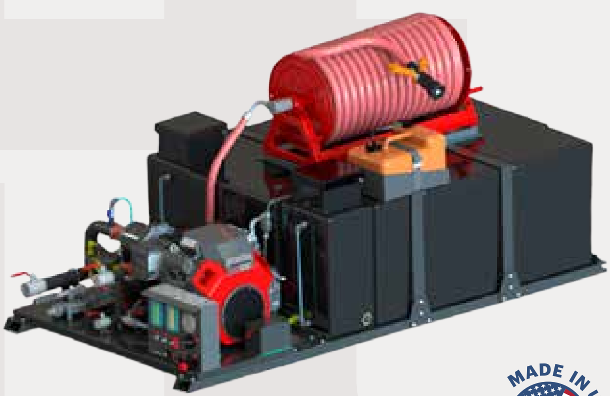

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Bomber 132, a C130H Hercules, lays a retardant line on the Bullengarook fire in Victoria, Australia, on Dec. 21, 2024. All photos by Wayne Rigg, AFSM, Country Fire Authority.

AUSTRALIA

MORE DATA REQUIRED TO DETERMINE AIRCRAFT EFFECTIVENESS

BY MATT PLUCINSKI, NICK MCCARTHY, OWEN PRICE, AND DEB SPARKES

Firefighting aircraft have become more common in Australia over the last few decades.

Current fleets, managed by states, territories and the federal government, comprise of a mix of light and heavy, fixed- and rotary-wing aircraft with a range of capabilities and capacities.

This fleet has evolved over decades through experience, with different aircraft models selected for different environments based on the accessibility of filling points, terrain and obstacles associated with built environments. Firefighting aircraft are more readily deployed to incidents than in the past and are often relocated across state borders in response to fires and anticipation of elevated fire danger conditions and related spikes in fire activity.

Wildfires are managed by state and territory governments in Australia; multiple agencies share responsibility within each state depending on land tenure and location.

Most aircraft are contracted from local companies, with larger aircraft bought in from overseas for the high fire danger period. Some agencies have recently begun to purchase aircraft, citing the need for avaibility during the whole year and a desire for multiple-purpose aircraft.

The unique geographies and arrangements within Australia's eight state and territory jurisdictions mean firefighting resources are used in a variety of conditions and applications. While aircraft are mostly used to drop suppressants and retardants, they also perform other important roles, such as intelligence gathering, supervision, transport and ignition.

There is little quantitative knowledge of, or data describing, how aircraft are used on Australian fires or how effective they are.

Most the existing operational understanding of suppression effectiveness is anecdotal, highly personal and difficult to compile. Most published data are limited to counts of hours flown, drops made and contracting costs. Inquiries after the devastating 2019-20 Black Summer fire season have made recommendations that research and evaluation into aerial firefighting be undertaken to address this lack of knowledge. The federal government has expressed support for this research and for evidence-based understanding of the capability required for an operationally effective fleet to meet current and future needs.

Knowing how aircraft are used during bushfire suppression operations is critical to understanding their effectiveness and will help provide a basis for promoting their effective use. This knowledge would also allow the comparison of usage patterns with intended use. Being able to identify situations in which aircraft are beneficial to suppression operations and those in which they are less so will enable the prioritisation of effective use and improve overall impact and cost efficiency. Restricting the use of aircraft in situations in which they are less likely be effective will also help to alleviate their scarcity and reduce aircrew exposure.

Effective suppression actions lead to desired outcomes for a fire. Successful outcomes can be more readily assessed when compared to explicit pre-defined objectives, which may include containment goals that relate restricting fire extent and impacts within specified time and spatial bounds. Assessing the effectiveness of high-cost resources, such as aircraft, should also consider their benefit in relation to lower-cost alternatives.

The availability of, and difficulty collecting impartial, representative and reliable operational data is a major limitation for bushfire suppression effectiveness research. There are also many diverse and interlinked variables that influence suppression effectiveness that must be considered when evaluating suppression effectiveness, such as those related to fire behaviour,

Helitak 367 dropping water on a large spot fire at the Creswick fire, which burned during extreme fire danger conditions in Victoria, Australia, on Dec. 16, 2024.

environmental conditions and the application of suppression.

Many projects have investigated aerial suppression in Australia, most notably Project Aquarius, undertaken by the Commonwealth Scientific and Industrial Research Organisation in the 1980s. Project Aquarius established some intensity thresholds for effective drops in some eucalypt forest types; the thresholds were used in an economic model that recommended fire agencies invest in more, smaller, geographically dispersed aircraft than fewer large aircraft that may be slower to respond to distant fires.

Another major project, funded by the Bushfire Cooperative Research Centre in the 2000s, confirmed the significant benefit that aircraft provide during initial attack, particularly for fires that take ground crews longer to access, and fires that occur during conditions conducive to rapid fire growth; the quick travel times for firefighting aircraft can help to minimise the size of fires for incoming ground crews so they have less fire to fight and a greater chance of early containment. The project made some field observations at wildfires and planned experimental fires but noted the significant challenges to the collection of sufficient quantities of data required to support detailed analysis.

In 2023, the Country Fire Authority launched a study to assess aerial firefighting tank systems and suppressants such as water foam and retardant. To date, 57 controlled tests have been undertaken, generating a structured dataset of aircraft and tank system drop patterns to define drop effectiveness in grassland and forest environments.

Some other smaller projects have reaffirmed benefits of the use of aircraft during initial attack while others have provided some case studies of aircraft use.

The findings of aircraft being particularly beneficial during some initial attack situations have been put to good use. Some Australian jurisdictions have developed pre-determined dispatch protocols that automatically send aircraft to first reports of fires above threshold fire danger triggers (before ground-based firefighting appliances request them).

From a theoretical economic perspective, the return on investment of aircraft is the greatest when such policy settings are optimised and fires are stopped early. However, the lack of data at a scientific standard to compare pre and post implementation of such policy means policy efficacy is very challenging to study.

Because incipient fires behave differently than steady state fires, and often the best intelligence on fire behaviour comes from aircraft, there is a paradox involved with not ever knowing if such fires needed the support that they received or not. To address this, fire agencies in Victoria are investing in fire reconstructions to collect the standard of data required to answer these questions. The focus for this work is on fires where a) the fire was a close call, meaning the fire was almost or

A medium helicopter, Helitak 339, defends a retardant line in dry eucalypt forest during the Bullengarook fire in December 2024.

just contained thanks to surge resourcing, and b) where there is sufficient data on fire behaviour to answer the questions.

While the benefits of aircraft during initial attack are well understood and documented, their use and effectiveness during extended attack and on larger fires are not. During initial attack, the objective for most suppression is simply to contain a new fire start as soon as possible, however, objectives can be much more varied for fires that have escaped initial attack efforts. This makes understanding the goals and effectiveness of aircraft use during large fires much more complex and is also likely why the subject has received very little research attention. This is concerning because large fires tend to have significant aircraft deployments that can persist for multiple days.

Aircraft tracking and event records are emerging as an important new data source for analyses of operational responses to fires. Aircraft that are contracted through Australia's National Aerial Firefighting Centre (NAFC) have been required to provide accurate and timely location and event reporting for a few seasons. This change requires the aircraft to be fitted with position-reporting, event-reporting, and messaging equipment and to transmit this data within minutes of collection. The data collection and transmission operate in the background without influencing operations, thereby providing a true representation of events.

The utility of this data for supporting research on aircraft use and effectiveness has only been explored in a single scoping study that examined data collected during a single season in one state. This study demonstrated that aircraft tracking and event data has great potential for supporting research; it also revealed some issues with completeness, in terms of numbers of aircraft being recorded, and the reliability of some fields, particularly those related to drop volumes and contents.

A further consideration for research using aircraft tracking and event data is that it can only provide some of the information required for studies of firefighting aircraft. Other data sources such as agency records (including fire progression isochrones, situation reports and intelligence logs), interviews with key personnel, and imagery and videography captured during operations, are required to provide critical information on suppression objectives, fire behaviour, environmental conditions and supporting suppression responses.

A new research project funded by Natural Hazards Research Australia and supported by NAFC and

Helitak 367 working on a grass fire in eaten-out fuels, with Country Fire Authority tankers, near Bung Bong in central Victoria on Jan. 22, 2025.

state and territory fire agencies will use event reporting data to investigate the application and effectiveness of aerial firefighting. The project, titled Why fly? How do we know that aerial firefighting operations are effective and efficient?, aims to describe the current aircraft-use profile and evaluate the effectiveness of aerial fire fighting across Australia using case studies compiled from a range of conditions and locations.

While the Why fly? project is a great step forward to enhance Australia's understanding of the use and effectiveness of aerial suppression, as a 1.5-year project, it will not be able to address many unresolved fire aviation effectiveness issues facing Australia and intends to make recommendations for further research and analysis.

Important issues, such as line productivity and holding, non-bombing aircraft benefits, cost effectiveness, and the effectiveness of retardants and suppressants are not being investigated in this project or any other current or planned research. For these reasons, continued improvements in data capture, completeness and availability are needed to increase the understanding of how aircraft, and other suppression resources, are applied and what they can and cannot be expected to achieve. These changes, along with further research into the many unresolved fire aviation issues previously listed, will help Australia work toward a safer, more effective and cost-efficient application of aircraft on the country's fires.

Matt Plucinski, Nick McCarthy and Owen Price contributed to the overview story on page 12; see their bios on page 14 and 16.

Deb Sparkes is the aviation research and evaluation manager at the National Aerial Firefighting Centre (NAFC), a business unit of AFAC. With extensive experience leading national bushfire management initiatives, Sparkes has played a pivotal role in projects such as the development of the new Australian Fire Danger Ratings System, prescribed burning guidelines, and Spark, Australia's newest bushfire simulation tool. Driven by a passion for knowledge exchange, Sparkes is committed to fostering collaboration and creating networks that spark innovation and drive progress.

VIRTUAL REALITY

AVIATION SIMULATOR RAISES SKILL LEVELS

BY DAVID BRUCE

The skills needed for air attack missions, fire mapping and other aviation-based wildfire operations are being improved in a new virtual reality simulator that provides real-life training.

The Australian-based mixed reality fire aviation simulator aims to improve the training and skills of those involved in fire aviation tasks, initially across Victoria with potential expansion to other states and internationally.

The aviation simulator uses mixed reality goggles with a 280-degree view of the surrounding landscape to provide training and skill testing in a safe, controlled environment.

Up until now, early training of this type needed to be conducted in actual crewed aircraft. The simulator has provided early-stage training to raise skill levels before conducting further training in real aircraft.

The simulator was launched in October at the Victorian Emergency Management Training Centre at Bangholme, Victoria.

The A$640,000 project was jointly funded by Victoria's Country Fire Authority and Department of Energy, Environment and Climate Action.

The aviation simulator was designed and developed by CFA Aviation Commander John Katakouzinos

More than 300 air attack supervisors and air observers have been trained using the new aviation simulator, including (pictured) Kelly Krajnc and Cameron Bird. Photos courtesy of Country Fire Authority Victoria.

originally as a mobile trailer, which is still being used by aviation members across the state alongside the new permanent facility.

The success of the trailer-based prototype led to the development of the permanent aviation simulator.

"The simulator allows aviation volunteers and staff to undertake mapping, air attack missions, direct aircraft and practise communication and radio skills in a simulated environment," Katakouzinos said.

"It replicates the interior of an aircraft and uses photorealistic mapping software and communication technology to immerse pilots and students in the flight experience.

"It's also designed to be programmed to train students in any scenario in any of the aircraft used for aerial firefighting in Australia, including re-enacting past operations for pre-season training."

Both the prototype and new permanent aviation simulators have achieved successful training outcomes with more than 300 air attack supervisors, air observers and airborne mission commanders trained or reaccredited in recent years. The simulator can be used at various stages of training, from initial expression of interest sessions and during accreditation and assessment, to skills upgrading and refresher sessions for those already qualified.

Country Fire Authority Chief Officer Jason Heffernan said the new aviation simulator at Bangholme, as well as the existing simulator trailer, were vital assets for aviation training.

"Aviation is important for providing intelligence and support to our crews on the ground during a fire and we're excited to be able to share this simulator with our partner agencies."

There has been interest from airborne partners with a portable aviation trailer being built for New South Wales Parks and Wildlife. The simulator is adaptable to all types of aircraft used in wildfire operations in Australia and internationally. The supporting software was developed by Wildfire Training Solutions in Canada.

David Bruce is the program manager and a former board member of the International Association of Wildland Fire. His career in media and communications roles has included being a journalist and an editor, and most recently the communications director at Natural Hazards Research Australia.

CANADA

AERIAL SUPPRESSION EFFECTIVENESS RESEARCH

BY MELANIE WHEATLEY, COLIN MCFAYDEN, RAZIM REFAI, EMILY HOPE, AND HEATHER SIMPSON

Canada's boreal zone spans more than 550 million hectares – an area larger than the European Union.

On average, about 8,000 wildfires ignite across the country each year, burning about 2.1 million hectares. During extremely active fire seasons – such as 2023 – up to 15 million hectares burned nationwide.

Despite these numbers, the boreal forest is a fire-resilient ecosystem and relies on wildfire for renewal and health. However, when fires threaten valuable forest resources, human lives, or property, wildfire suppression tactics come into play to minimize unwanted impacts.

Suppression or control of wildfires with airtankers is a core strategy for most Canadian provincial and territorial wildfire management agencies. Airtankers include fixed-wing and helicopter aircraft that drop water, retardant, or other suppressants onto wildfires.

Across Canada's vast forests, a variety of airtankers are used, each suited to different fire conditions and landscapes.

Skimmer airtankers, which scoop water from lakes, are commonly used in areas with abundant waterbodies such as Eastern Canada. Land-based airtankers, which rely on airport refueling, are more common in regions where lakes are fewer or harder to access, such as some areas in Western Canada and the northern territories.

A variety of aerial firefighting equipment availble in Ontario, Canada, during the wildfire season.
Photo courtesy of the Ontario Ministry of Natural Resources, Aviation, Forest Fire and Emergency Services.

Some regions use both types of aircraft, combining the advantages of direct suppression with the skimmer airtanker that drops suppressant right on the flames, and indirect suppression, with land-based airtankers that drop suppressant ahead of the fire to create a barrier.

Helicopters equipped with water tanks or buckets are also widely used because they can pick up water from small lakes and rivers and manoeuvre through tough terrain.

Provinces and territories secure and operate their airtanker fleets in different ways. Some regions own and operate their own fleets of fixed-wing airtankers, some contract aircraft (and crew) from specialized suppliers, and others do a mixture of both. Helicopters (rotary-wing airtankers) are generally contracted based on demand. But no agency is left to fend for itself when fire activity exceeds the number of airtankers available.

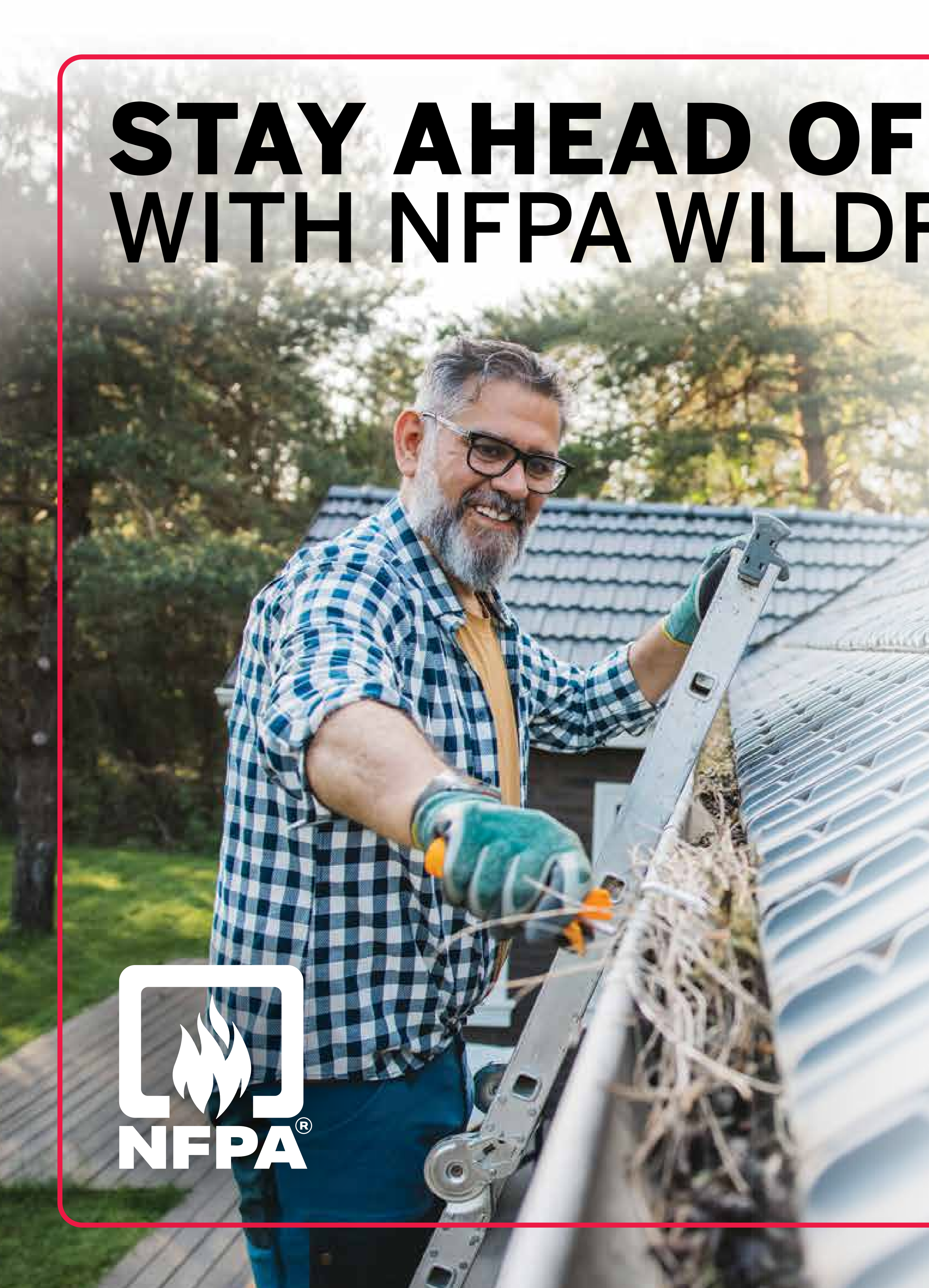
The Canadian Interagency Forest Fire Centre (CIFFC) helps coordinate the sharing of aircraft and personnel across the country and internationally, ensuring that agencies can share resources and response effectively to wildfire. The record breaking 2023 fire season in Canada presented a historically unprecedented level of resource demand. Canadian agencies received assistance (firefighters and overhead personnel) from 12 countries. Considering climate change, it's expected that 2023 may not be anomalous, but rather a signal of a new normal.

Leveraging research to improve suppression effectiveness in wildfire operations

Innovation in the aviation space to support wildfire suppression has its history deeply rooted in Canada. The use of airtankers to deliver water – commonly referred to as waterbombing – originated in Canada in the 1940s when pilots in northern Ontario began experimenting by dropping waxed paper bags of water or mounting water drums on aircraft to assist ground crews with suppressing fires. Since then, Canada has continued to innovate and conduct research on airtanker suppression effectiveness. Research in Ontario in the 1990s guided agencies toward an optimal configuration for their airtanker fleets – the type and number of aircraft needed to meet average fire demands.

The complex problem of defining and measuring the effectiveness of airtankers is not straightforward and therefore requires studying the operational use of airtankers in many stages throughout the fire-response process. The current research in Canada is examining the operational use of airtankers including deployment strategies, dispatch prioritization, and understanding and maximizing the effectiveness of airtanker use on fires.

One of the challenges fire managers face is day-basing – a question of where, when, and how many airtankers to pre-position in strategic locations. Researchers in Alberta and Ontario are developing airtanker positioning models to support decision making and resource prioritization.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Canadian fire management agencies and researchers collaborate on field-based aerial suppression experiments. Andrew Reid, air attack officer (left) is coordinating the tactical plan for suppression on the experiment. Melanie Wheatley, research scientist (right) is communicating the science plan and recording observational data associated with fire behaviour and suppression. Photo courtesy of CIFFC Ontario Ministry of Natural Resources.

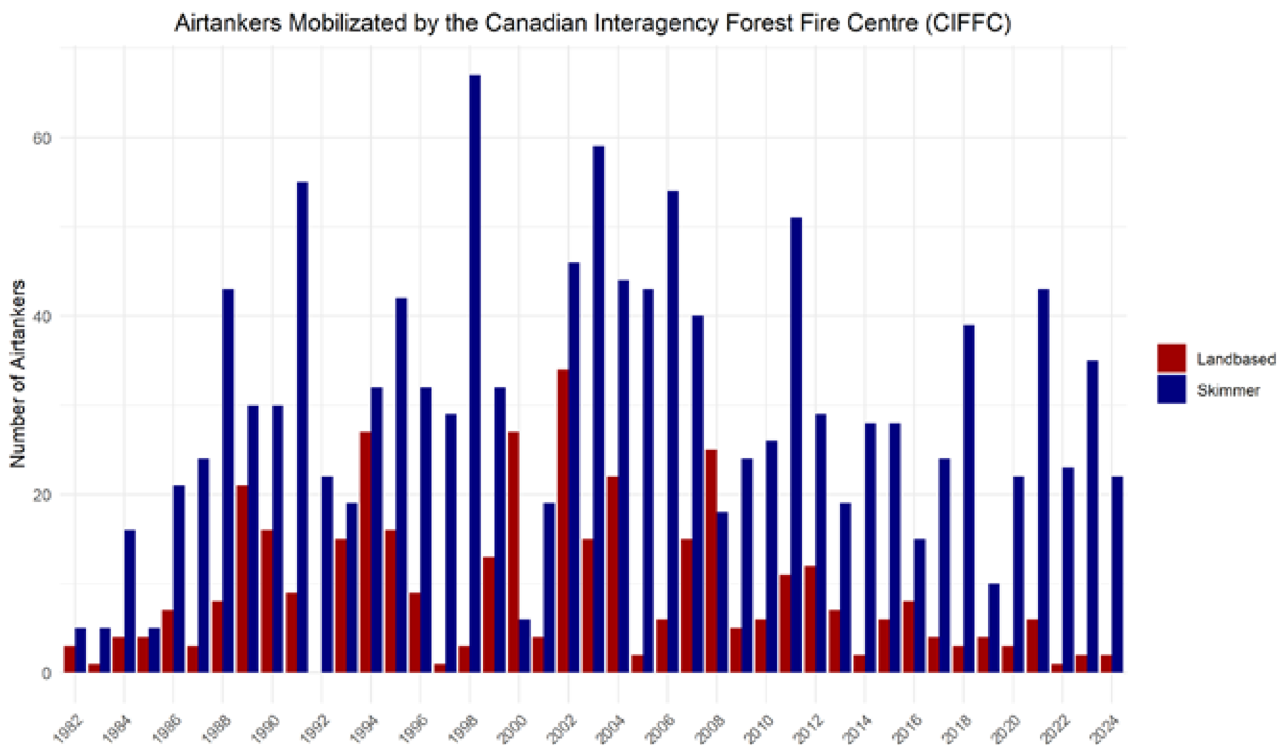
To lower initial attack response times, a typical approach is to use pre-set rules such as attack radius, response time and fire hazard to identify optimal locations to position airtankers. Studies in British Columbia and Ontario use historical fire and airtanker use data to identify factors that influence airtanker dispatch during initial attack, insights that can be incorporated in optimization simulation models.

Understanding how well airtankers work in real-world operations is critical. In Ontario, researchers have used detailed observations from skimmer airtanker missions recorded from trained air attack officers who are deployed with the airtankers, recording operational mission data including detailed observations of fire behaviour directly observed from the fireline, along with the volume of suppression applied during a skimmer airtanker mission. This data was used to develop statistical models that quantify the ability of CL-415s to reduce fireline intensity on both initial attack and for sustained action missions. These models present the required amount of suppression to reduce fire behaviour to a smouldering state given various levels of pre-suppression fire behaviour. Importantly, because of the ability of the CL-415 to scoop water from nearby lakes resulting in fast turnaround-times, the findings indicate that in Ontario, the CL-415 airtanker can be effective at higher intensities than previously indicated by current operational suppression effectiveness thresholds used across Canada – an important finding to guide future airtanker use.

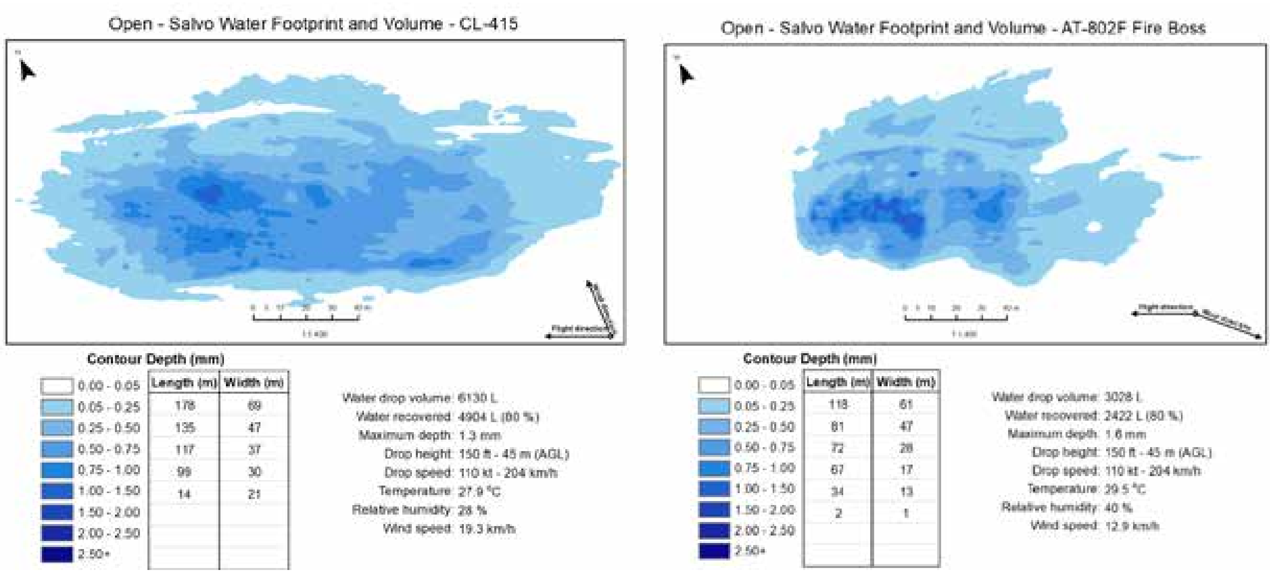
Theoretical models, based on what we know about the physical properties of how water and fire interact, have been developed to assess and compare the effectiveness of different skimmer and rotary-wing airtankers used across Canada's boreal. In 2023, the Ontario Ministry of Natural Resources and Natural Resources Canada published the Reference Guide to the Drop Effectiveness of Skimmer and Rotary Wing Airtankers – a valuable tool for fire management agencies to compare the effectiveness of these different airtankers under varying levels of fire behaviour. Efforts are ongoing to communicate these findings to fire operational personnel.

Because wildfire is a dynamic and complex process, fire management research must go beyond the theoretical science. Field-based research – research on actual wildfires – is considered a gold standard to understanding not only fire behaviour but airtanker suppression effectiveness.

Before examining airtanker suppression on wildfires in the field, an understanding of drop pattern, or footprints of airtankers, is important. Efforts to study and quantify drop patterns, which measure the distribution and depth of water, suppressant, or retardant dropped by airtankers, date back to the 1960s. More recently,



Total cumulative number of aircraft (broken down by skimmer and land-based airtanker) mobilized from 1982 to 2024 by the Canadian Interagency Forest Fire Centre. Over the last 10 years, an average of 24 skimmer airtankers and four land-based airtankers are mobilized across Canada each year (this does not include short-term support such as cross-boundary quick-strike coordinated through localized compacts). Plot is re-created from https://www.ciffc.ca/mobilization-stats.

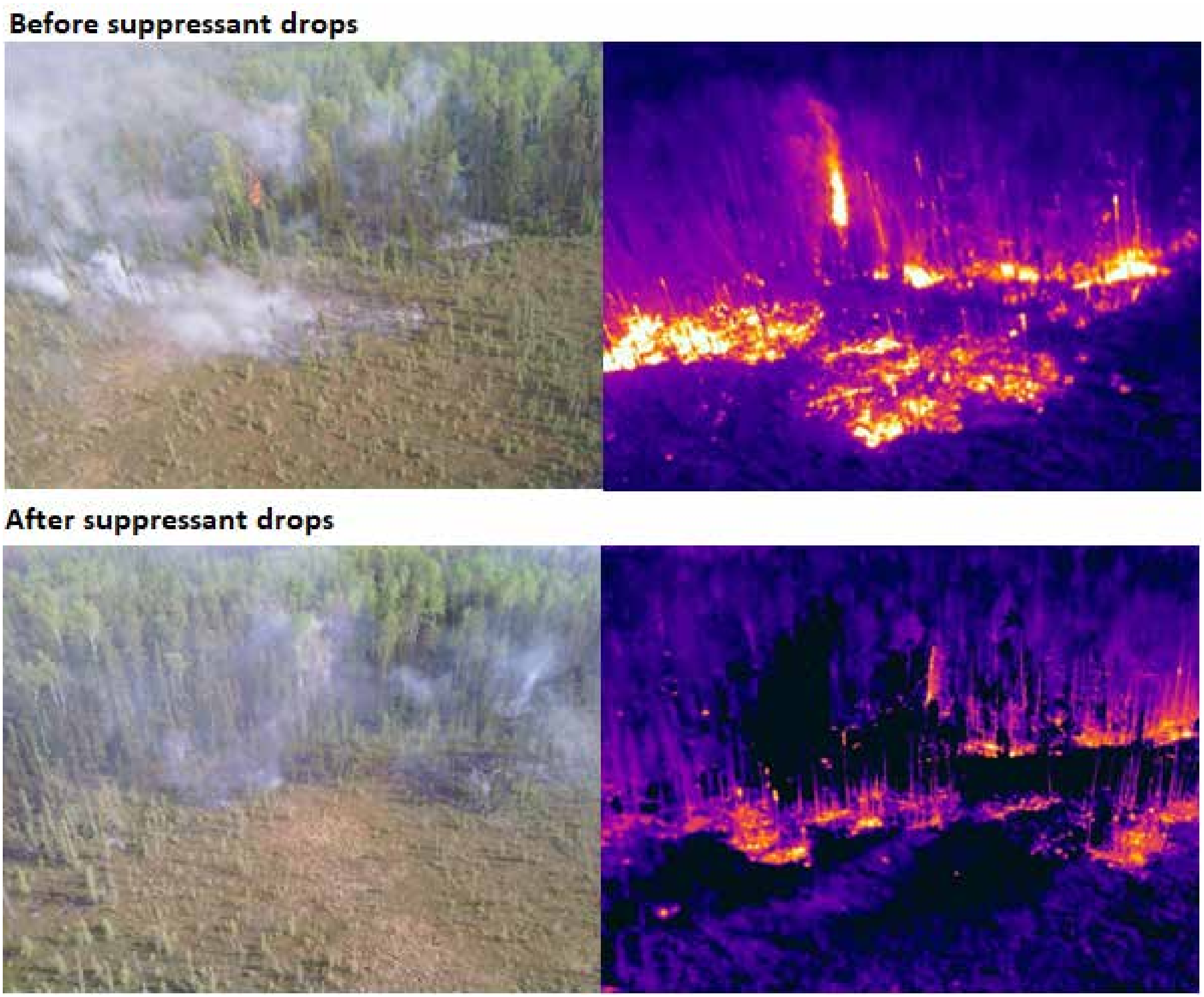


Drop footprints developed for the CL-415 airtanker (left) and AT-802F Fire Boss (right). Footprints can be found in McFayden et al. (2023): Reference Guide to the Drop Effectiveness of Skimmer and Rotary Wing Airtankers.

Canadian research firm FP Innovations, the Ontario Ministry of Natural Resources, and Natural Resources Canada developed drop patterns for airtankers used across Canada. Various airtanker types – including the Canadair CL-215T, Canadair CL-415, AT-802 Fire Boss, AT-F802F, Sikorsky S-61N, Bell 212, and others – have been tested across open fields, forested, and fuel-treated stands. Using a modified cup-and-grid method, where hundreds of cups are placed on the ground in a large grid to measure the amount of water, suppressant, or retardant collected after each drop, researchers have documented the coverage levels and drop footprints of these aircraft that are commonly used in Canada (see photos below).

Building on our understanding of airtanker drop footprints, recent field experiments have examined the impact of airtanker suppression action on active wildfires. FPInnovations and Alberta Wildfire have conducted several field-based studies that explore impacts of suppression from both rotary-wing and land-based airtankers. Studies involving helicopter tankers (Sikorsky S-61N) emphasized effectiveness in direct attack applications while those involving land-based airtankers (Dash 8-Q400AT) looked at retardant effectiveness in indirect attack applications. Methods used in these studies relied on airborne thermal infrared imagery to collect data from a helicopter (figure 3). These research methods are also being used to explore the effectiveness of suppression activities from night-vision system aided helicopters for actioning fires at night.

In 2024 the Ontario Ministry of Natural Resources, The National Research Council of Canada and Natural Resources Canada initiated field research to test the effectiveness of the CL-415 on wildfires in Canada's boreal forest. Researchers, paired with fire behaviour experts and operations staff, used an infa-red



Thermal imagery is used to study the effectiveness of suppressants on active wildfires.

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imaging-equipped helicopter positioned above CL-415 suppression activity to record the associated impact on fire behaviour. This project leverages an experimental design where controlled replicates of airtanker drops are applied in real-world settings to try to limit variability in observations as much as possible. This innovative methodology will process the infa-red imagery to provide detailed estimates of fire spread and fireline intensity, attributes that fire managers commonly used to support their decision making. These field-based studies are necessary to form a baseline scientific understanding of airtanker effectiveness, which will be the foundation of future studies related to optimizing airtanker use in fire management.

There is plenty to learn about how to support the optimization of airtanker use during operations and plan for their long-term role in wildfire management.

The execution and implementation of this research requires close collaboration between those who use the aircraft and those who research them. Canada is fortunate to have strong collaborative relationships between researchers and fire managers, a relationship that is strengthened through networks such as the CIFFC Aviation Working Group, a national group of aviation fire managers who share knowledge on aviation-related challenges in fire management and support innovation to address those challenges.

Agencies play a key role in the research process by identifying research needs, sharing operational data, providing expertise, and supporting field studies that directly measure airtanker performance. Researchers bring the analytical tools and scientific methods to refine and expand our understanding of aerial suppression effectiveness. By combining operational expertise with research, Canada continues to refine its approach to aerial fire fighting, ensuring a safe, effective use of aviation resources to support wildfire management for years to come.

Writers Melanie Wheatley, Colin McFayden, Razim Refai, Emily Hope, and Heather Simpson contributed to the overview story on page 12. See their ios on pages 14 and 16.

A large airtanker makes a water drop on the Summit Trail Fire in Washington in July 2021. Photo by Colville Agency, Bureau of Indian Affairs, courtesy of National Interagency Fire Center / NIFC Flickr.

UNITED STATES

EVALUATING THE EFFECTIVENESS OF LARGE AIRTANKER DROPS

BY DAVE CALKIN, CAL BRYAN AND JIM RIDDERING

There has been a small but growing body of research within the United States on the use and effectiveness of aviation over the past 15 years; much of this focused on large airtankers.

Studies have focused on understanding where and when aviation drops occur, how fire managers prioritize the use of aviation, optimal fleet design, and how risk management concepts can inform where and when to most effectively apply aviation.

The most expansive research effort to date was the Aerial Firefighting Use and Effectiveness (AFUE) study initiated in 2012 to "systematically document the operational utilization and tactical contribution of aerial firefighting resources that have the ability to deliver water and wildland fire chemicals in support of incident objectives."

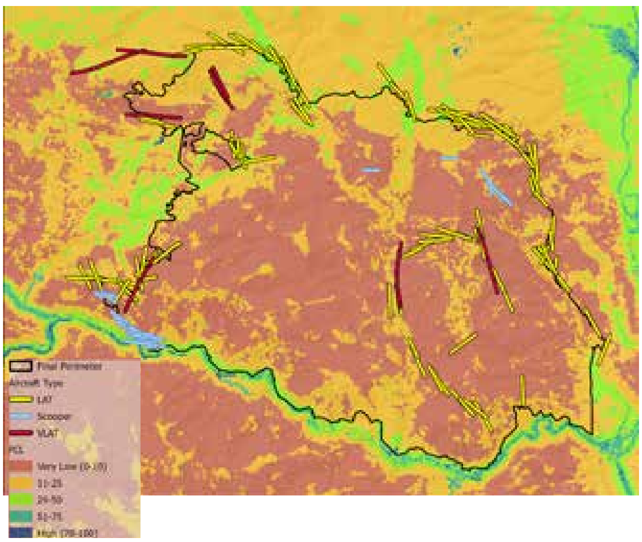
As part of the AFUE study, the research team coordinated with incident commanders to collect data on aviation use on 272 wildfires from 2015 to 2018, including more than 5,000 airtanker retardant drops. The research team recorded the primary suppression objective for each retardant drop based on radio communication, operational briefings, and/or post-hoc conversations with incident management. Drops were then categorized into a variety of different outcomes, including no fire interaction, burned through, halted fire spread, and others. The research team then created performance metrics to measure the likelihood of aviation drops interacting with wildfire and their probability of success.

The AFUE study included observations for a variety of aviation platforms dropping water and retardant.

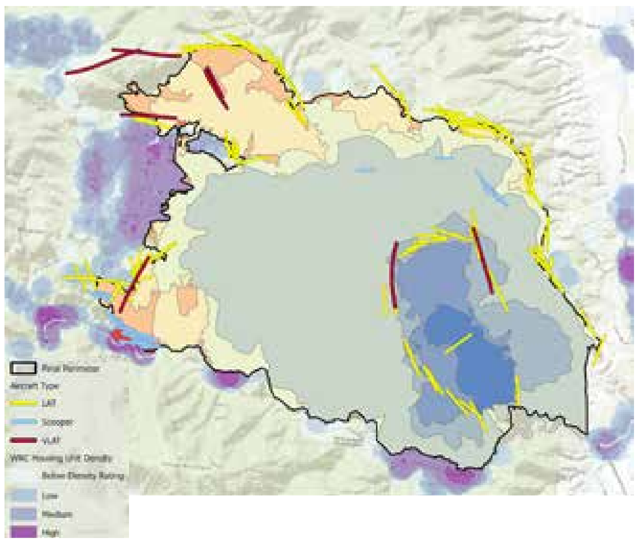
Halting fire spread and delaying fire spread were the two most common objectives for retardant drops, each representing more than 40 per cent of drop objectives with point protection coming in a distant third at 10 per cent. About one-quarter of all large airtanker (LAT) drops did not interact with the final fire perimeter, demonstrating the use of airtankers for indirect suppression tactics and contingency line development. Not surprisingly, for those drops that interacted with wildfire, the probability of successful drops intended to halt fire spread was lower (55 per cent) than the objective of slowing fire spread (75 per cent) and point protection (87 per cent). Although the AFUE study provided a level of detail regarding drop objectives and relative measures of success, there was an important question unanswered: do these mission objectives truly alter wildfire outcomes during extended attack?

Researchers at Colorado State University are engaged in a study to provide formal calculations on the effectiveness of large airtanker retardant drops at altering wildfire growth. The researchers use data provided by units mounted inside LATs that record the exact locations and times of retardant drops, along with information on the daily growth of wildfires from 2017 to 2019, to evaluate fire characteristics before and after the wildfire passes over the retardant line. The researchers evaluate the change in wildfire characteristics as the fire moves through a swath of land that is split by the retardant line. However, a critical piece of information to understand the effectiveness of LAT suppression at the drop level is a comparison with areas unaffected by retardant.

To ensure accurate comparisons, the researchers measure wildfire outcomes in adjacent areas with similar vegetation and topography. The key difference? These areas lack retardant lines, serving as a control, thus creating what is known as a natural



An overlay of airtanker drop locations with the Potential Control Locations. Fires have a high likelihood of stopping in areas with cool colors (blue and green) and low likelihood in hotter colors (red and orange). The image shows drops on the Alexander Mountain Fire in the Pike San Isabel National Forest in Colorado in 2024. Graphic by Jim Riddering.



Aviation drops relative to daily fire progression and populated areas on the Alexander Mountain Fire in Colorado in 2024. Heavy retardant use during the first several days of the event were unsuccessful in stopping the fire, requiring operations to fall back to more favorable locations near populated areas. Graphic by Jim Riddering.

experiment. The difference in the change in wildfire outcomes as the fire moves through these two swaths of land provides statistics for the effectiveness of LAT retardant drops.

The researchers evaluated the effectiveness of LATs at halting wildfire progression, reducing the intensity, and delaying the spread of wildfire; they found that LATs are effective at altering wildfire outcomes in all three ways.

Wildfire is 8.4 per cent less likely to spread into land that is protected with an LAT drop compared to land that is not buffered by retardant.

Similarly, the intensity of fire (measured by the gridded Monitoring Trends in Burn Severity layer) is 7.5 per cent lower for land protected by a retardant line.

Land protected by retardant takes four to five hours longer to burn than unprotected areas, giving crews crucial time to respond.

These findings reveal the tangible impact of LAT drops on wildfire behavior, offering key insights for suppression strategies.

These statistics aggregate the effectiveness of retardant drops across a variety of landscape and weather conditions. However, the Colorado State researchers have found that LATs are more effective across all three dimensions when dropping on land covered with shrub vegetation, compared to areas dominated by grass or trees. They have also found that air tankers can delay the spread of wildfire by more than 30 hours when used in conjunction with other types of suppression, and that tankers classified as very large airtankers, or VLATs, based on larger tanks for holding retardant, can reduce the likelihood of fire spreading by roughly 12 per cent relative to land not protected by any retardant drops. This research also provides assessment of the influence of

topography and general weather conditions on drop line effectiveness.

Understanding the effectiveness of large airtanker drops is a crucial step in refining wildfire suppression strategies, but translating research results into actionable feedback for incident management teams remains a challenge.

Developing processes to review past actions and provide near real-time information to the field is essential for improving future wildfire responses and maximizing the effectiveness of airtanker use.

As such, researchers and fire managers have been using additional telemetry units (ATUs) to track various metrics associated with air tanker drops. ATUs are mounted on all federally contracted airtankers (and some single engine airtankers – SEATs). ATUs are GPS-enabled devices that track parameters such as aircraft location, time, heading, altitude, and most importantly, tanker door open and close events.

ATU data have been used since 2017 to calculate air tanker drop locations and associate various analytics with those drops. These original aviation-use summaries (AUS) were manually produced and provided to fire managers through the US Forest Service's Risk Management Assistance (RMA) dashboard to help inform how fire chemical and water were being applied to the landscape. Additionally, the AUS process can be used as a powerful after-action review of the effectiveness of aviation drops in supporting suppression actions. Original metrics associated with the AUS reports focused on analyzing time of day, fuel types, and slope classes where the drops were occurring. Subsequent AUS development used the rise of integrated metrics such as suppression difficulty index (SDI) and potential control locations (PCL) within the RMA dashboard to provide additional context for managers to evaluate the use of air tanker drops on incident strategy and tactics.

An airtanker drops retardant on the Peavine Fire at sunsetin June 2020. This fire was near Reno, Nevada. Photo by Sarah McNeil, Bureau of Land Management / NIFC Flickr.

In June 2025, the National Interagency Coordination Center mobilized federal firefighting personnel to support wildfire suppression efforts in Canada (Manitoba, Saskatchewan, and Alberta). This cross-border support is made possible through a long-standing agreement between the United States and Canada, first established in 1982. It's a partnership rooted in shared landscapes, common challenges, and a mutual commitment to protecting lives, property, and natural resources. Photo by US government, courtesy of NIFC/Flickr.

More recently, US Forest Service personnel have worked to automate the processing of ATU data to expedite the production and distribution of airtanker drop information and associated analytics. Daily processing starts by creating lines from ATU GPS point data for door open and door close events. These derived drop lines are then extended to account for forward momentum of the fire chemical or water. Next, drop lines are buffered and values for SDI, PCL, slope, elevation (of the line), and majority fuel model are extracted for the buffer, and appended back to each drop line feature class (Figure 1). A significant amount of processing time is devoted to quality assurance to remove redundant or bad data points and ensure the creation of logical drop lines. Problematic lines are flagged as possible false positives but retained in the database. Other attributes added include split drop information (where a tanker will split the load and do multiple drops in one flight), the calculation of various time parameters, and incident name association. The final step updates an ArcGIS Online (AGOL) Feature Service. The feature service feeds an AGOL dashboard that is available to credentialed managers and users. Work continues to improve estimation of gallons dropped and tracking costs associated with flights.

Through the automated processing and near-real time distribution, users such as incident management team members, aviation officers, and coordination center managers are better able to monitor drop locations (including areas of misapplication), assess the use of air tanker resources on their incident, and build knowledge using derived analytics to help them evaluate the effectiveness of air tanker resources.

This work highlights the importance of integrating research findings with managerial experience to determine effective resource use. Dan Dallas, an incident commander with the US Forest Service in Colorado and early adopter of the AUS system explained the value.

"The AUS provides us the ability to examine recent drops in near real time on fires we manage giving us the information necessary to identify where and when aviation could best support suppression actions. Using the AUS to examine our management of past events allowed us the opportunity to think more clearly about how aviation can best support our incident strategy. This has allowed us to clearly articulate our strategy in aviation use to the hosting unit and our field-going personnel. We firmly believe the use of AUS has significantly improved the effectiveness and efficiency of our suppression actions and overall fire strategy."

Aerial drops are probably the most iconic and visible

Wildland fire suppression efforts on the Clear Fire, Fairbanks Area in Alaska.Photo by Eric Kiehn, Kittitas County Fire District 1.

activities in wildfire suppression and often a critical component to initial attack and large fire suppression strategies. The effectiveness and efficiency of wildfire suppression actions writ large is poorly understood, and we largely rely on the experiences of incident management team members and field-going firefighters to determine what resources are needed and where they should engage.

Aviation is but one component of wildfire suppression and the coordination of the broad array of ground and aerial resources is a highly complex process.

The AFUE study provides an indication of the type of objectives and conditions of effectiveness but did not uncover how objectives contribute to overall fire suppression outcomes.

Given the costs of wildfire suppression, exposure of ground and aviation personnel, and the impacts to natural and developed resources, improving the effectiveness and efficiency of wildfire management is essential and understanding aviation's role will be critical to that effort. Progress will be contingent on the ability for researchers and managers to work together to foster more safe, effective, and efficient solutions.

Dave Calkin contributed to the overview story on page 12; see his bio on page 14.

Cal Bryan is a post-doctoral researcher in the Agricultural & Natural Resource Economics department at Colorado State University, interested in researching methods to optimize operational resources for fighting large-scale wildfires. Bryan holds a bachelor's degree in bioenvironmental sciences from Texas A&M University, a master's degree in economics from San Diego State University, and a PhD from Colorado State in agricultural and natural resource economics. Bryan's PhD dissertation, titled Evaluating the Efficiency, Equity, and Effectiveness of Wildfire Suppression Strategy Using the Microeconomic Toolkit, focuses on determining patterns in large airtanker use across wildfires in the United States and their effectiveness at altering wildfire outcomes. Before starting graduate school, Bryan spent several years working seasonally for the U.S. Forest Service in various roles, including trail crew supervisor, interpretive ranger, and type-II wildland firefighter.

Jim Riddering is an aviation analyst with the Strategic Analytics Branch of the U.S. Forest Service Office of Fire and Aviation Management. Riddering's responsibilities include managing the Additional Telemetry Unit (ATU) program, developing data processing streams, and providing analysis of aircraft use. Riddering holds a PhD in forestry from the University of Montana and has more than 20 years of wildland fire experience, including time on hotshot and engine crews. Riddering is a qualified Aerial Observer (AOBS), holds a private pilot's license (SEL), and is working on completing his Long-term Analyst (LTAN) qualification.

SOUTH AFRICA

GOVERNMENT-FUNDED PROGRAMME BOOSTS AERIAL RESOURCES

BY TREVOR ABRAHAMS

Aerial firefighting has become a staple component of South Africa's approach to combating unwanted wildfires and limiting the devastating impacts of such fires. Its emergence as a critical defence system dates back to the period after the devastating fires in South Africa's plantation forests in the 1980s. As in other parts of the world, aerial firefighting resources are recognized as necessary measures to combat large fires, complementing the firefighters on the ground.

"The coordination between aerial and ground crews is key to the success of firefighting operations," said Johan Heine, founder of the Working on Fire programme. The Working on Fire programme is a government funded public employment programme targeting unemployed youth who are trained to serve as certified wildland firefighters; they are deployed at 230 bases across South Africa and abroad in countries such as Canada, Indonesia and Chile.

The introduction of aircraft to combat fires from above significantly improved response times, enabling quicker containment and minimising losses. Aerial fire fighting not only saved the South African commercial forestry industry from collapse but became an integral part of

the current wildfire management strategies that protect South Africa's natural environment.

South Africa typically experiences two fire seasons. The summer fire season is December to April in the southern part of the country, which is a winter rainfall region, and the winter fire season is June to October in the northern and eastern parts of the country, which experience summer rainfall. This seasonal character of the fire season has allowed a relatively limited fleet of aerial resources to cover a country of some 1.2 million square kilometres. However, the impact of climate change has introduced an element of unpredictability as some of the largest recorded fires have occurred in areas out of the normal fire season.

South Africa has three broad fire prone biomes: the savannah bushveld; the grasslands; and a Mediterranean-like fynbos area along the southern coasts and mountains and the cultivated commercial plantation forests. The fire risk in South Africa is exacerbated by the prevalence of alien vegetation infestations, such as eucalyptus, wattles, and hakea originating from Australia, and pines from Europe and North America, which propagate wildfires at a fiercer rate and are more demanding on ground water than indigenous vegetation.

In 1981, the commercial forestry industry studied methods employed in North America and initially contracted aerial bombers (Ayers Thrush with 500-gallon hoppers) together with spotter command and control aircraft. Subsequent disaster wildfires in 1985 increased the demand for aerial firefighting resources and gave rise to growth in this aspect of wildland fire management in South Africa. At this point, South Africa also developed a single dispatch centre for coordinating the deployment of both ground and the growing number of aerial resources to wildland fires.

A wide variety of aircraft have been used in firefighting operations in South Africa. The current fleet of aerial firefighting resources includes agricultural application aircraft that are deployed in some areas seasonally to dedicated firefighting operations as part of the Working on Fire programme; these include 10 Thrush 400/500s, five AT802s, four AT502s, 14 Hueys, one Black Hawk, one Bell 212, five Squirrel B3s and some 14-C182, C206 and C210 light aircraft deployed as command and control aircraft.

Initial use of Bell Jet Ranger helicopters equipped with underslung Bambi buckets soon gave way to larger Russian Mi-8s and Kamovs, which arrived in South Africa in 1990 seeking work after the dissolution of the Soviet Union, and later the introduction of the Bell UH-1 Iroquois, commonly known as the Huey, after the original UH-1 designation. The helicopter fleet also serves as essential trooping vehicles for firefighters responding to wildfires in the mountainous and remote areas of South Africa.

The Huey was originally developed and certified by the United States military in 1959 and became the iconic helicopter in the Vietnam War. With its capacity to carry a Bambi bucket holding around 1200 litres of water, the Huey has become a familiar sight in South African skies. Renowned for its reliability and relatively low operating cost, the Huey remains a preferred choice in aerial fire fighting in South Africa. There is also a single version of the Black Hawk helicopter (2500-litre load) that flies alongside a fleet of 14 Hueys and five AS350s (800-litre load) currently operating in South Africa.

The Russian Mi-8 and Kamov helicopters – modified for firefighting purposes – can carry up to 3500 litres and 5000 litres of water respectively. While these aircraft offered powerful firefighting capabilities, they also came with significant operating costs and were ultimately excluded from South African operations by the South African Civil Aviation Authority. The South African Air Force also occasionally provides support with Oryx helicopters during disaster fires.

The fixed wing bomber fleet started with the rotary-engine Dromader (2500 litre load), which was replaced with the purpose-built Air Tractor 802, one of the leading single engine airtankers deployed in firefighting operations globally. The AT802 can carry more than 3000 litres of water and chemicals via a computer-controlled water dispensing system.

South Africa has a somewhat unique role for its command-and-control Spotter aircraft, typically high-wing Cessna 182s, 206s or 210s. "Unlike its bird dog counterparts in some other parts of the world, the command-and-control firefighting aircraft in South Africa borrowed from the military forward command and control aircraft which guided its artillery and assumes the role of the air boss over the fire," said Heine, one of

A Kishugu JV Huey helicopter at the Pringle Bay fire in the Western Cape, South Africa on Jan. 30, 2024.
Photo courtesy of Working on Fire.

A Kishugu Air Tractor 802 bombs the Knysna fire in 2017. The Knysna fire in was the most destructive wildfire in South Africa's recent history; six lives were lost, including two firefightes, and more than 900 structures burned. Photo by Deidre Cloete.

the first spotter pilots employed in South Africa and the founder of Kishugu Aviation.

These aerial command and control aircraft play an essential role in coordinating wildfire suppression efforts and act as the eye in the sky for incident commanders. They provide real-time intelligence and aerial surveillance via a live video link, act as an onsite air traffic control, directing aerial bombing resources making tactical decisions about where to direct water bombing and communicate between ground and air units. Equipped with high-resolution cameras and advanced communication systems, the command-and-control aircraft tracks fire behaviour, monitors its spread, and identifies high-risk areas. By maintaining a bird's-eye view, it enables incident commanders to make informed decisions regarding resource deployment, evacuation strategies, and suppression tactics. Furthermore, it enhances safety by identifying hazards that may not be visible from the ground, such as shifting winds or isolated fire outbreaks, ensuring that firefighting efforts remain efficient and responsive to changing conditions. To do so, these pilots are trained in fire behaviour, wildland firefighting tactics and are in constant communication with all firefighting aircraft, ground teams and the incident commander.

Aerial water bombing in South Africa serves an indispensable role in delivering water to fires in remote and often inaccessible areas. These bombing drops typically consist of water mixed with a two per cent wetting agent to enhance the impact and penetration of water bombing through the vegetation. Water sources for the helicopters vary from ponds and rivers to dams, private swimming pools and sea water for fires close to the coastline. This results in a very rapid turnaround between drops. The fixed wing bombers, however, return to landing strips close to fire prone areas and usually have a five-minute reloading turnaround time.

As in most countries, South Africa's aerial firefighting resources, (excluding the occasional use of military helicopters) are privately owned and operated. However, the government-funded Working on Fire programme also includes support for aerial firefighting. The expanded public works programme has grown to employ 5300 firefighters and is supported by Kishugu Aviation's 10 Hueys, four AT802s, 14 Spotter aircraft and a contracted Black Hawk helicopter.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Other than the national government funded Working on Fire programme, provincial governments, municipalities in fire prone regions, conservation agencies, and fire protection associations enter various contractual arrangements to give them access to the country's aerial firefighting resources. The Western Cape provincial government has an innovative golden-hour grant, through which it pays for the first hour of aerial resources for any wildland fire in the province, thus facilitating rapid deployment of aerial resources and resulting in many fires being contained within the first hour of detection.

The extent of the wildland fire threat in South Africa outstrips current aerial firefighting resources and sometimes the costs associated with such resources inhibits its use at precisely the time when it could make a significant difference. This is particularly the case as wildland fires, under the influence of climate change, are increasingly extending into the 'food basket' grasslands and savannah in South Africa.

The growing impact of climate change will necessitate greater international collaboration in aerial fire fighting. Europe has already led developments in this regard, and sharing of pilots and aircraft is also likely to feature in the future of wildland fire management. It is imperative that forums such as the International Fire Aviation Working Group (IFAWG) be resuscitated across the globe to facilitate meeting this challenge.

Trevor Abrahams is the managing director of the Working on Fire Programme and chairperson of the Kishugu Aviation Division (Pty) Ltd board of directors. He previously established the South African Civil Aviation Authority and served as the Commissioner for Civil Aviation between 1998 and 2003. Abrahams obtained his commercial aircraft and certified flight instructor certificates from the USA Federal Aviation Authority while studying in the United States in the 1980s.

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FRANCE

STUDYING DROPS TO PROPOSE A BETTER SYSTEM

BY FRÉDÉRIQUE GIROUD AND DOMINIQUE LEGENDRE

Research and experiments on airdrops in France began with the first LABEX (LArgage Bombardier d'eau EXperimentation) experiment in 1995.

Following the acquisition of CL-415 waterbombers by the French government, it quickly became apparent that to optimize aerial fire fighting, it was necessary to understand the dropping characteristics of the aircraft.

Entente Valabre, the laboratory of the French Securité Civile, oversaw measuring the ground patterns of the French waterbomber fleet.

The aim of the LABEX research is to determine the ground patterns of various water-bombing aircraft and analyze the ground distribution of the released product by application rate class.

Each aircraft comes with a range of dropping programs. To optimize aircraft use in aerial forest fire fighting, it is essential to know the surface areas covered by the different applications – how much area is covered and by what depth of drop.

Various camera views of retardand drops show specific factors that help to determine effectiveness. Photo courtesy of Entente Valabre.

To complement these experiments at a real scale, with real aircraft, other experiments are carried out to understand and model aircraft drops are conducted. Analysis by Entente Valabre researchers of the airtanker ground patterns show that the product is not deposited uniformly, and is often deposited very irregularly, because of a complex fragmentation process of the liquid column released by the aircraft.

Although the release process seems simple, the fluid dynamics governing the transformation of a liquid block into a cloud of droplets are only partially understood. The droplets can be neither too fine to avoid dispersion and evaporation, nor too large to avoid harsh impacts on vegetation and the ground, resulting in projected objects. Large-scale fragmentation of a drop, which leads to the formation of liquid meteors that take longer to atomize into droplets, is a complex process and its physical origin is unexplained.

DETERMINATION OF GROUND PATTERNS

Ground patterns are evaluated on flat test areas, free of vegetation or covered only with herbaceous vegetation up to a height of 20 centimetres.

The test area dimensions are determined according to the aircraft to be tested and the areas is set up in a grid. The drop patterns are measured by distributing receptacles over the test area, comprising a fixed support and a collection cup designed to catch the liquid. After each test, the cups are hermetically sealed, collected and weighed. Each pattern is then plotted on a predefined scale, corresponding to classes of application rate in litres per square metre per day, or litre/metres².

DETERMINING RELEASE EFFICIENCY

The ground-pattern efficiency is primarily related to the application rates obtained, depending on the product released – water or retardant. In the Mediterranean region, under normal conditions of vegetation (10 metric tonnes per hectare), weather (wind less than 60 km/h) and terrain

The drop patterns are measured by distributing receptacles over the test area, comprising a fixed support and a collection cup designed to catch the liquid. After each test, the cups are hermetically sealed, collected and weighed.

(not generating excessively difficult trajectories or significant turbulence), a rate of 0.8 lm2 is representative of an effective release using long-term retardant, while a rate of 1.6 l/m2 is representative of an effective release using water.

The various ground patterns parameters are:

- The length and depth for coverage rates above the representative application rates
- The area and product volume above representative application rates
- The homogeneity of the ground pattern
- The difference between the time the drop hits the ground and the time it totally covers the ground.

Ground pattern extension and concentration levels are not the only release characteristics that can determine the effectiveness of a drop. The speed of the released product can have a considerable influence on breaking fire-induced updrafts during direct attack, on upwind accuracy, or on safety on the ground. All these factors can be qualitatively related to the phases of ground-pattern formation. The three phases – retardant cloud tearing, atomization and dispersion – explain the various stages that take place between the initial break-up of the product cloud and the formation of droplets that have reached their final size. The rheology of the product, the height and speed of the aircraft, and the release system play an important role in these phenomena.

Observation of the drop is very important to assess its effectiveness, and valuable information can be gleaned from camera images. For this reason, a few subjective criteria are selected:

- Frontal view (cohesion, drift, separation phenomena, expansion, tearing)
- Lateral view (core erosion, deformation, disintegration, forward velocity)
- The status of the cloud when it hits the ground and the way it disperses while resting on the ground.

PRESENTATION OF RESULTS

The ground patterns are presented in the form of summary sheets in which the following are described:

- technical flight data (altitude, aircraft speed)
- technical loading data (weight, volume)
- meteorological conditions
- ground patterns characterization.

Following these analyses, recommendations are made regarding the use of different dropping programs for specific firefighting missions, for example initial attack or retardant-barrier construction.

EXPERIMENTAL CAMPAIGNS IN FRANCE

Five experimental campaigns have been conducted in France:

- LABEX 1996: Canadair CL-415, Hercules C130, Fokker 27, Tracker 2SF
- LABEX 2009: Dash 8 Q400, Canadair CL-415, Tracker 2SF
- LABEX 2013: Air Tractor AT-802
- LABEX 2021: Dash 8 Q400 with retardant
- LABEX 2024: Dash 8 Q400 with water

DROP MODELING

LABEX campaigns are time consuming and costly; therefore, it is essential to have a dropping model that can be used to vary, for example, the height of the drop, the wind direction and the characteristics of the product released – questions that water bomber pilots frequently ask to understand and optimize their practice.

With this in mind, a team at the Institut de Mecanique des Fluides de Toulouse is developing a dropping model that has already been tested against results obtained during various LABEX campaigns.

Initially, the approach was based on ground patterns from the US Department of Agriculture Forest Service's open-access technical reports, which made it possible to study and model the main characteristics of a ground footprint, namely its length, width and density of deposited product.

The use of numerical simulation as a tool for predicting the drop cloud produced by an aircraft appears to be very attractive for gaining access to all the physical mechanisms involved. However, the computing resources available, even at the biggest French and European computing centers, do not currently allow researchers to describe the entire process from the aircraft to the ground.

The three phases – retardant cloud tearing, atomization and dispersion – explain the various stages that take place between the initial break-up of the product cloud and the formation of droplets that have reached their final size.

An approach developed by PhD candidate Corentin Calbrix in his thesis for Universite de Nimes was limited to describing the fragmentation of the released liquid in a zone close to the aircraft, i.e. 10 metres below the aircraft. Computational fluid dynamics studies of the CL-415 and Dash 8 drops were carried out, showing that fragmentation and dispersion in this zone prefigured ground deposition 50 metres below, which could be deduced by extrapolation of the drop cloud envelop. This approach can now be used to study drops by these aircraft under various operational conditions, particularly in the presence of crosswinds, to help interpret the differences in ground patterns observed during LABEX and provide useful information to optimize forest fire fighting.

Frontal and lateral observation of the release during a LABEX is an essential element in assessing the quality of a release. The eye can identify the quality of product fragmentation and dispersion and anticipate the characteristics of the ground pattern. Packages with a higher concentration of liquid are generally easy to observe and are likely to generate areas of higher concentration on the ground, making the ground pattern less uniform and of poorer quality.

The explanation for this fragmentation mechanism is not yet available: Is it a physical instability intrinsic to fragmentation at this scale, or the memory of a disturbance transmitted to the fluid by the release system? To answer this question, studies are underway at the Institut de Mecanique des Fluides de Toulouse combining wind tunnel experiments and numerical simulation.

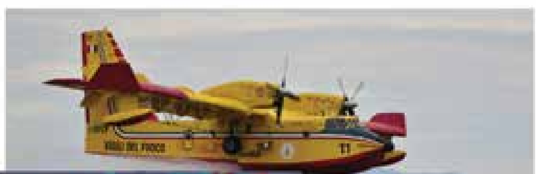
A one-tenth scale dropping device has been installed in the 2.4 metre diameter wind tunnel, capable of delivering up to 25 m/s of relative wind. The fragmentation of the liquid column is filmed by a high-speed camera at 2,000 frames per second. The first results of the water release show a specific fragmentation mechanism that cannot be explained by literature results at smaller scales.

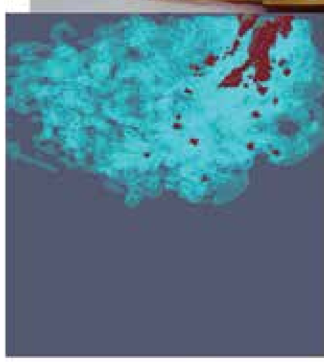
A computational fluid dynamics (CFD) code benchmark is underway to challenge various French and American research codes for the study of this instability; these codes must be able to reproduce wind tunnel experiments before the study of fragmentation at aircraft scale can begin.

Ultimately, understanding the origin of the instability and its modes will lead to proposals for better designs for release systems.

The aim of the LABEX research is to better understand and optimize aerial forest fire fighting. It is essential to know the different firefighting missions of aircraft to provide recommendations on the use of the different drop programs available on each aircraft. Climate change leads to changes in fire behavior, and the missions of firefighting aircraft must be adapted to these new phenomena. The tools and experiments described above will be used to improve existing dropping systems, to validate their operational use, and to assist pilots in the understanding of their practice.

Writers Frédérique Giroud and Dominique Legendre contributed to the overview story on page 12. See their bios on page 14.





A liquid drop in the wind tunnel at the Institut wind de Mecanique des Fluides de Toulouse and computational fluid dynamics of a Canadair CL-415 drop. Images courtesy of Entente Valabre.

PROMOTING CHANGE THROUGH VISION

BY MIKE DEGROSKY

The fundamental purpose of leadership is to create and promote change, to move people and organizations from their current state to a desired state.

People engaged in leadership are the subjects of change but, more so, the driving force behind it. It matters not whether one leads a squad of firefighters, a research lab, or a large organization; without a vision of the organization's future, there is no leadership.

Creating and articulating a vision of a desired future is a leadership necessity. Whether the organization is a fire crew or an entire large agency or organization, effective leaders must identify and relentlessly communicate a collective vision that answers the question "Where do we need to go?"

Visionary leaders do not answer that question only for themselves; they communicate their vision and ensure that those they lead understand the organization's direction. Visionary leaders also involve people, knowing that an excellent vision rarely emerges from solitary efforts. Truly effective leaders offer much more than the generic vision statements that organizations often use to decorate their walls; they articulate clearly where their organization is going and what people need to do to get there.

A well-communicated vision is navigational, providing direction for the organization; it is like a star guiding people to the future the organization wants for itself.

I define organizational vision as a realistic, credible, desired future for an organization. Some people refer to organizational vision simply as a desired future state.

I do not know why, but people struggle with "the vision thing," as a former president of the United States said. However, the business purpose of vision is not tough or mysterious. In fact, it is quite simple. The leader's vision describes what he or she wants the organization to look like or what he or she wants it to be in the future. Vision is the leader's description of a condition toward which the organization should work. At the most fundamental level, vision describes the organization's destination.

On this topic, I have long been influenced by Burt Nanus, a professor emeritus of management at the University of Southern California School of Business Administration, who, in his book *Visionary Leadership,* stated, "There is no more powerful engine driving an organization toward excellence and long-range success than an attractive, worthwhile, and achievable vision of the future, widely shared." That philosophy shaped me, not only as leader but as a strategic advisor to other leaders, and it has never let me down.

Vision and leadership are inseparable. In the United States, statements of vision by prominent figures have famously and fundamentally altered the course of our nation. President John F. Kennedy's vision of

Vision is a core leadership value that provides the foundation of organizational culture, inspires people, guides decisions, and helps people set and achieve goals.

putting a man on the moon and Martin Luther King Jr.'s "I have a dream" speech inspired America to move beyond the status quo to achieve what, at the time, seemed almost unimaginable. However, a vision of success can also be much more utilitarian. A crew boss telling the crew that the intent is to complete and hold fireline from their current position to the division break by noon is vision, the desired end to which all will contribute.

Which reminds me of a long-ago quote by the late management guru Jack Welch, who had been the CEO of General Electric during its heyday. "Good business leaders create a vision, articulate the vision, passionately own the vision, and relentlessly drive it to completion," Welch said. While business professors might argue that Welch's vision ultimately led to GE's demise, I share his thoughts on the relationship between vision and individual leadership. Similarly, John Kotter, an emeritus professor of leadership at the Harvard Business School and an influential author and business consultant says, "Effective leaders help others to understand the necessity of change and to accept a common vision of the desired outcome." I like that description of a leader's role.

The relationship between vision and leadership is an area that has been well studied. For example, Israeli researcher Taly Dvir and her colleagues found that a leader's vision embodying transcendent elements is associated with increased levels of emotional obligation that an individual makes to an organization, including willingness to remain with the organization, pride in and promotion of the organization, internalizing team success, a feeling of "family," and a sense of meaning and belonging. Along these lines, communicating vision represents a key component of transformational leadership theory that underlies most contemporary leadership approaches – the idea being that transformational leaders get followers to put forth extraordinary effort to accomplish a vision of an optimistic and attainable future.

Vision is a core leadership value that provides the foundation of organizational culture, inspires people, guides decisions, and helps people set and achieve goals. I cannot think of a leader I have seen accomplish much without a powerful, well-communicated vision that people had gotten behind. I regard the ability to establish and articulate a desired future state, and rally people to it, as an essential leadership skill and believe that without vision, there is no leadership.

Mike DeGrosky is a student of leadership, lifelong learner, mentor and coach, sometimes writer, and recovering fire chief. He taught for the Department of Leadership Studies at Fort Hays State University for 10 years. Follow Mike via LinkedIn.

RELATIONAL WELLNESS

NURTURING RELATIONSHIPS DURING WILDFIRE SEASON

BY BEQUI LIVINGSTON

All aspects of wellness are equally important to maintain balance. Relational wellness is often minimized but is so critical to our wellbeing.

Humans are hard-wired for connection; we need safe and healthy relationships. Yet, when stressed, such as during wildfire season, our closest relationships often take the hardest hit. Just look at the divorce rate in the wildland fire community, which is similar to that of combat veterans during wartime. Being in wildland fire can have an impact on our partners, children, families, friends and pets. It doesn't have to be this way if we are aware and informed of simple strategies to help us navigate the challenges that come with working in wildland fire.

Do you have enough energy at the end of a fire assignment to give to those people (and pets) that are dearest to you, or do you return home after a hectic assignment not wanting to have meaningful conversations, feeling irritable, or reverting to maladaptive coping mechanisms? These signs might not show up until fire season is in full swing, as your body slowly adapts to the traumatic stress of one fire assignment after another. Our closest relationships are what matter most; those who will be waiting for us when the fires go out and we return home – spouses, partners, children, parents, friends, family, siblings, pets and coworkers who support us and help us find our footing. These precious relationships need to be nurtured before, during and after wildfire season.

I met my husband Ron during a wildfire in Colorado in the summer of 1988. I was on the Smokey Bear Hotshot crew and assigned as the division helispot manager while Ron, a Vietnam veteran combat helicopter pilot, was flying and supporting our division. After getting married I resigned to help Ron run our helicopter business and raise our children. I came back to work in 1995, on the Sandia Ranger District, outside Albuquerque, New Mexico, eventually becoming the district assistant fire management officer. By then, Ron had sold the helicopter business and began working for the Federal Aviation Administration, which required lots of travel.

We were a dual-career couple, requiring a lot of balance and honest communication to make our relationship work, especially as parents. Luckily, Ron knew the wildfire business, and all that came with it. I knew when I accepted the job that my family would always come first, and I had amazing bosses who were supportive, as they too were parents. However, it didn't come easy and took a lot of dedicated effort between my husband and me to make things work. I learned that our closest relationships are the most precious thing, and family should always come first. In fact, there were many times that we would get a wildfire call right at quitting time, and I had to turn it over to someone else because I had to pick up my kids from childcare when Ron was traveling. I didn't designate someone else to pick them up, because, as a mother, that was my priority, and I wanted to make sure that wildfires never interfered with my family.

It wasn't easy, but with lots of communication and some useful tools (listed below), we've made it work for 36 years. We learned ways to prioritize and manage our relationship, and although I was lucky to have a spouse who understood wildland fire, others are not so lucky. My son was a wildland firefighter for several years, and his girlfriend, (who is now his wife) was always afraid and uncertain of what to expect. That truly opened my eyes to what other partners and family members go through during fire season. It's such a hard job to understand, especially for our most cherished relationships – for good reason: they are afraid of what might happen to their loved one. Crazily enough, our four adult children are now first responders, and one is a former combat veteran helicopter pilot, so these tools are essential for their partners and families.

To maintain healthy relationships as a wildland firefighter, it's critical to practice some essential skills. Remember that your loved ones are equal partners in your wildland world, often experiencing stress and trauma much like your, even if they aren't on the fireline.

Prioritize open and honest communication.

Learn how to talk openly, and honestly about your feelings and experiences, including the difficult situations, and be willing to listen to your partner's concerns, without judgement. Talk openly about any issues you may both be experiencing, using "I" statements, for example, "I feel ________ when __________ because ________". Never place blame on each other, rather speak about your experience. If you're still hyped up on the stress of work, take time to calm down, gather your thoughts and breathe before having a conversation.

Engage in active listening to your partner.

Be fully present and pay close attention to what your partner says, validating their feelings without minimizing, interrupting, or becoming defensive. The key aspects to healthy communication are feeling safe and feeling heard without shame or judgement.

Maintain flexibility with schedules.

This is important for any situation but especially for dual-career couples, to understand that wildland fire work schedules and travel demands can be very unpredictable, especially during fire season. Have a contingency plan that covers all the bases, especially if you have younger children.

Understand the emotional impact of the job.

This is really important due to the stressful aspect of the job and to the families left at home. It's nice to have a safe space to decompress after a fire assignment or stressful shift to unwind and let your nervous system settle before re-engaging with family, friends and work. It's important to provide time to talk to your partner and family about any emotional impacts or concerns they may be experiencing. Most importantly, if you find yourself, or loved ones in an emotional crisis, or in need of support; reach out for help.

Set clear expectations.

Discuss your needs and boundaries regarding work-life balance and time together, especially during fire season. It's OK to say no and ask for what you need, as well as what you don't need.

Practice self-care.

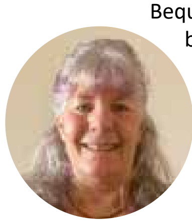
This is a priority. Like the flight attendant always reminds us in the safety briefings, always put your oxygen mask on before helping others. It's OK, and actually quite brave to do things that make you feel good and help you relax – simple things like getting a massage, taking a walk in nature, fishing, or enjoying music can help make you a better partner and parent.

Prioritize quality time together.

Make a conscious effort to schedule time as a couple or family to connect without the stress of the job. Work will always be there, but your kids will grow up and leave the house before you know it.

As my good friend and I used to tell firefighters while teaching our workshops, there are no do-overs or go-backs in life, especially when you have a family.

We typically have one chance in our relationships to do the right thing, the right way. Wildland fire is a rigorous occupation, often taking us away from those we love, while missing out on important milestones. We always have a choice to do the right thing in all our relationships.



Bequi Livingston was the first woman recruited by the New Mexico-based Smokey Bear Hotshots for its elite wildland firefighting crew. Livingston was the regional wildfire operations health and safety specialist for the U.S. Forest Service in Albuquerque, New Mexico. Contact her at bequilivingstonfirefit@msn.com