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# The Economics of Wildland Firefighting Aviation Procurement and Effectiveness

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## Abstract

We examine two economic aspects of aviation used for wildland firefighting in the United States. First, we analyze the procurement of aviation resources by federal agencies, and how the structure of contracts influences suppression costs. Second, we highlight the lack of empirical evidence on the effectiveness of aviation and provide a research design to quantify effectiveness and the benefits of aviation use. Our analysis can inform tactical operations on individual wildfire incidents and help federal agencies develop season-long resource utilization strategies.

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## Introduction

Over the past ten years, the federal government has spent an average of \$2.3 billion per year on wildfire suppression (NIFC, 2023). These costs are expected to rise as climate change drives more intense fires over longer seasons (Abatzoglou and Williams, 2016; Burke et al., 2021). Approximately 21% (\$493 million) of that \$2.3 billion is spent on aviation resources (Stonesifer et al., 2021). These costs involve hourly flight costs to operate the aircraft, the cost of retardant, and the cost to keep the aircraft available. Given the high cost of aviation, it is critical to determine whether the benefits of their application exceed the costs. Otherwise, resources could be better invested in other firefighting resources such as wildland firefighting engines, dozers, and personnel (Stonesifer et al., 2021).

The procurement of aviation resources influences federal expenditure on firefighting aviation. For nearly the past two decades, federal firefighting agencies have contracted with private companies that own and maintain firefighting aircraft. Currently, federal agencies lease and own aircraft. In the case of leased aircraft, contracts are structured in one of two ways: a near season-long, exclusive use agreement or short-term contracts which generally carry a price premium. The structure and prices of these contracts and the procurement mechanism influence how aviation resources are used and the costs borne by firefighting agencies.

The objective of this paper is to describe and analyze two economic aspects of aviation used for wildfire response. First, we apply economic principles to the procurement of aviation resources and discuss how federal agencies may improve economic efficiency. Second, we discuss how the benefits of aviation are not well measured or tracked, making it difficult to conduct benefit cost analysis. This paper aims to frame the economic problems associated with the use of aviation and provide a path forward for solving them, although it will not arrive at clear conclusions.

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Wildfire response is a coordinated effort between federal, state, and local land management agencies. Firefighting resources include hand crews, engines, dozers and aircraft. These resources are owned by different agencies but will coordinate under unified command when incidents become large and complex. When multiple fires are burning, resources are allocated according to need and agency officials' expectation of benefit on specific fires (Bayham and Yoder, 2020). Aircraft are one of the most visible firefighting resources and are used to drop water and retardant on or in advance of the fire, deploy smoke jumpers, gather information about the extent and intensity of the fire, and survey damage. While aviation can provide valuable services, they are one of the most expensive resources on an active fire.

## **Procurement**

Aircraft have been used in wildfire response since WWII (Pyne, 1982) when military aircraft were retrofitted with equipment that would allow them to carry and drop water. Over the years, government agencies have acquired, retrofit, and maintained a fleet of airplanes and helicopters, some of which were owned, and others leased from private entities. While the fleet of firefighting aircraft is diverse, including various sizes of helicopters, small airplanes, and modified commercial jets, much of the federal aviation fleet is now leased from private entities. The reasons for leasing aircraft include the high cost of ownership, the flexibility associated with variation in fire activity throughout the year, the ability to use modern aircraft without having to frequently cycle inventory (Thompson et al., 2012).

Aviation contracts are complex legal documents, but generally include numerous safety requirements, a daily availability price, and an hourly flight price. The two forms of contract are exclusive use (EXU) and call-when-needed (CWN). Exclusive use contracts mandate that an aircraft is exclusively available to the contracting entity (e.g., US Forest Service) for a specified number of days at a daily cost. Call-when-needed contracts are more flexible and can be activated on short notice (Thompson et al., 2012). However, CWN contracts specify a daily availability rate and hourly flight rate that is higher than EXU contracts. The question is: how many of each contract should the USFS sign at the start of each fire season?<sup>3</sup> The answer depends on expected use patterns of the aviation resources. We focus on this question in the context of large and expensive aircraft known as Large Airtankers (LAT) and Very Large Airtankers (VLAT) classified based on their water and retardant capacity. However, our general approach could be applied to other aviation resources as well.

Expected use patterns are a function of fire activity throughout the season. If the demand for aircraft were equal on every day of the season, it would be optimal to sign all exclusive use contracts for the season. If demand were intermittent but known throughout the season, it would be optimal to sign CWN contracts (up to a certain daily cost rate differential), so that one only pays for aviation when it is needed. The reality is somewhere in between these extremes. Wildfire activity is largely driven by predictable weather patterns starting in the spring in the southwestern US, progressing north and counterclockwise across the northwest through the summer, and ending in California in the fall (Westerling et al., 2003). However, the fire activity on any particular day throughout the

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<sup>3</sup> While the agency may also choose to own and maintain their own aircraft, we only consider the choice between existing contract types because the USFS has shown a reluctance to own and maintain aircraft in recent years.

season is very unpredictable. Therefore, the optimal portfolio of contract types depends on the variability and uncertainty in demand throughout the season.

Figure 1 illustrates the variability and uncertainty of initial attack fires (bottom panel) and large fires being actively suppressed (extended attack - top panel) throughout the season. According to the 2022 USFS Schedule of Items, most large airtankers under exclusive use contracts started between March and May and were scheduled to end in September, October, or November.<sup>4</sup> While the eighteen large and very large airtankers under contract in 2022 span the dates when fire activity is expected to be high, they are not activated in a pattern that follows the number of IA and EA fires in Figure 1. The trends in Figure 1 suggest that, given current usage patterns, the USFS could delay activating some Large Airtankers (LAT) and Very Large Airtankers (VLAT) until later in June. Call-when-needed contracts could be used to handle surge capacity and unexpected increases in fire activity.

While a procurement strategy aligned with historical usage patterns may be more cost-effective in expectation, there are political consequences of having too few aircraft under contract when more are available. In the wake of a destructive wildfire, the public often asks what more firefighting agencies could have done. If aviation resources could have stopped a fire from spreading or protected homes, public and political pressure would provide the incentive to contract more resources than necessary - a result of risk aversion.

The objective of an optimal portfolio is to meet operational demands at the lowest cost possible. We focus on the decision between EXU and CWN contract types rather than the agencies owning and maintaining aircraft. The agencies have avoided owning their own aircraft because of the cost of maintaining an aging fleet. However, if the cost of leasing becomes high, agencies may reconsider ownership.

Developing a strategy based on historical usage patterns assumes that aviation resources have been used efficiently in the past. In the context of aviation use, efficiency means that aircraft are used in a way that generates the most benefit. For instance, an aircraft should drop retardant in a location that provides the most protection to valuable assets. However, the benefits of current aviation use patterns have not been quantitatively analyzed. The next section describes existing analyses of aviation use and outlines a quantitative approach based on causal inference methods in econometrics.

## Measuring the Benefits of Aviation

Cost-benefit analysis requires the accounting of the costs and benefits of an intervention over a relevant time period (Boardman et al., 2018). The financial cost of using aviation to fight fire is recorded because the government is responsible for payment.<sup>5</sup> The benefits of aviation are broad, including the deployment of retardant for direct suppression, monitoring the fire and resources, and transporting people and equipment. We focus on the benefits of direct suppression in this analysis. These benefits are hard to quantify because they involve the avoided costs and losses of fires that

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<sup>4</sup> The only publicly accessible document we could locate was from June 24, 2022.

[https://www.fs.usda.gov/Internet/FSE\\_DOCUMENTS/fseprd1041508.pdf](https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd1041508.pdf)

<sup>5</sup> There are other costs of using aviation, including the risk to pilots that fly in dangerous conditions around challenging terrain and the external costs of the retardant. Butler, O'Connor, and Lincoln (2015) document that 78 of the 298 (26%) recorded wildland firefighting fatalities were attributable to aviation incidents between 2000 and 2013. The external costs of applying retardant are not well studied, but they are the subject of a current court case (Brown, 2023).

were prevented from growing and damaging valued assets. If aviation resources reduce the probability that a fire spreads and damages property, we do not observe the counterfactual - what would have happened in the absence of aviation use. This section describes how aviation resources are currently used to fight fire, discusses the conceptual challenges to measuring benefits, and proposes data-driven approaches to measuring the benefits of aviation, given currently available data.

Aviation resources such as large airtankers (LAT) are believed to be most effective during the initial attack phase (the first burning period, which is usually from ignition to 10:00 AM the following day) (Calkin et al., 2014). The logic is simple: aggressively attack the fire while it is small, and it will not grow large. Most fires (more than 90%) are contained during initial attack (Holmes, Huggett, and Westerling, 2008). However, the fires that do escape initial containment because of weather or lack of sufficient IA effort can grow large and threaten values at risk.<sup>6</sup>

Aviation is increasingly used to support extended attack - the incident phase after the first burning period. Indeed, (Stonesifer et al., 2016) find that in 2010 aviation was used on IA 63% of the time (see Table 3 in (Stonesifer et al., 2016)). By 2012, aviation use on IA represented only 44% of drops. A US Forest Service Aerial Firefighting Use and Effectiveness (AFUE) Report documents that between 2015 and 2018, aviation resources were used on extended attack 60% to 70% of the time (AFUE, 2020). Aviation resources may be used during extended attack to contain or slow fire spread, reduce burning intensity, and reinforce fire lines built on the ground (AFUE, 2020).

The fundamental question is: when is using aviation to fight fire worth the cost? The answer depends on the objectives of the mission, which aircraft are conducting the mission, and tactically where on the fire aviation is used in relation to other suppression activities. The AFUE report finds that across all types of aviation, there is an 82% success rate in accomplishing mission objectives.

Despite the advances in understanding aviation effectiveness, the AFUE report does not apply a study design capable of measuring the benefits of aviation. Researchers collaborated with forest stakeholders to produce performance metrics and evaluation criteria for analyzing aviation use on wildfires, including whether retardant or water drops reduce fire intensity, delay fire growth, or extinguish the fire. Whether the objective was accomplished or not was subjectively assessed by agents in the field rather than through objective measurement by instrument. These methods are susceptible to human biases that may want to show that aviation resources provide benefits.

Here, we define a study design intended to measure the benefits of aviation objectively and quantitatively. Specifically, we outline a difference-in-differences (DiD) approach to assess the probability that an aviation drop stops or reduces the intensity of the fire. The time and location of aviation drops are recorded by an automated telemetry unit that is required on all contracted aircraft. We can build a dataset that includes the time and location of the drop, the fire progression, landscape characteristics, and weather. We know the location of the drop and the direction that the fire is burning, so we can spatially define the area in front of the drop (pre-treatment) and the area after the drop (post-treatment). The challenge in any causal inference problem is to find an appropriate control to serve as the counterfactual. In this case, we can define a control as the area adjacent to the end of

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<sup>6</sup> Values at risk is an umbrella term which captures assets that society values, including private property, infrastructure, cultural heritage sites, and endangered species habitat.

the aviation drop. The area near the end of the drop is likely to have similar vegetation and topography that influences wildfire behavior.

Figure 2 illustrates the empirical strategy on a retardant drop on the Terek fire that burned in Wyoming in 2018. The fire is progressing south, and retardant is dropped in advance of the fire. The drop is 529 meters long. The north side of the drop (A) is the pre-treatment region, while the south side (B) is the post-treatment region. The control region is east of the retardant line, with the north and south similarly defined as the pre (C) and post-period (D). In this example, the fire does not progress south of the drop into region B, but it does progress into region D (post-period control area), providing some evidence that the drop prevented the spread of the fire to the south.

We cannot draw conclusions from a single drop. We repeat this procedure across many drops on many fires. Once the regions are defined for each drop, we can use geographic information systems (GIS) to extract information on vegetation, topography, and weather conditions at the time the fire encountered the drop. The following model can be used to estimate the average treatment effect of the drop,

$$y_{it} = \alpha + \beta_1 Treated_i + \beta_2 Post_t + \beta_3 (Treated_i \cdot Post_t) + \gamma X_{it} + \varepsilon_{it},$$

where  $y_{it}$  is the outcome variable for unit  $i$  at time  $t$ . The outcome could be a binary indicator for whether an area burned or a measure of intensity like Fire Radiance Power.<sup>7</sup>  $Treated_i$  is a binary variable indicating whether unit  $i$  is in the treatment group (region A and B in Figure 2).  $Post_t$  is a binary variable indicating whether the observation is from the post-treatment period (region B and D in Figure 2).  $X_{it}$  is a vector of vegetation measures, topography, and weather, and  $\varepsilon_{it}$  is the error term. The coefficient of interest is  $\beta_3$ , which represents the treatment effect. The coefficient of interest measures the difference in the change in fire outcomes between the treatment and control groups before and after the treatment.

The identification of the treatment effect is based on the assumption that the precise location of the start and end of the drop is as good as random. The pilots intend to drop retardant in an area, but the exact location is subject to pilot accuracy, speed, altitude, and weather conditions. If the end points of the retardant drop are quasirandom, then the untreated region near the drop is just as likely to be treated.

This framework is simple but powerful. First, it produces a causal estimate of the average effectiveness of large airtanker drops toward stopping the spread of fire. Second, we can easily investigate the heterogeneity of the treatment effect by interacting topography, vegetation, and weather with  $(Treated_i \cdot Post_t)$ . These results can help inform strategic operations, highlighting when and where large airtanker drops are most effective. The results also serve as a crucial step in estimating the benefits - avoided damage - of LAT drops. For example, at time  $t$ , assume there is some risk to assets denominated by  $\rho(e_0) * V$  where  $\rho(e_0)$  is a probability of loss as a function of effort,  $e_0$ , and  $V$  is the dollar value of the assets at risk.<sup>8</sup> If a LAT drop represents effort  $e_1 > e_0$ , then

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<sup>7</sup> Fire Radiance Power is a quantitative measure of energy detected by satellites observing fire activity. These data are generated and shared by NASA's Fire Information for Resource Management System (FIRMS) (<https://earthdata.nasa.gov/firms>), part of NASA's Earth Observing System Data and Information System (EOSDIS).

<sup>8</sup> We use the term asset to include private assets like homes and property as well as public assets such as ecosystem service values. The value of homes is generally well-understood because transaction prices are observable. Ecosystem



the benefit of the drop is  $V * [\rho(e_0) - \rho(e_1)]$ . This benefit is comparable to the known cost of the flight based on the hourly cost and cost of retardant.

## Conclusions

A changing climate is driving longer and more intense fire seasons. There is an urgent need to reduce wildfire risk in fire-prone regions of the US. Yet, the primary method for reducing risk at the landscape level involves the costly removal of combustible fuels. Despite significant progress, the number of acres in need of fuels reduction treatment is very large and not expected to be treated over the next decade (Thompson et al., 2023). Wildfire suppression and response currently does, and will continue, to play a key role in protecting people, property, and other valued assets from wildfire. As federal firefighting agencies seek to improve the efficient use of resources, the procurement and use of aviation resources presents several opportunities.

The current structure of procuring aviation resources involves exclusive use and call-when-needed contracts. Federal agencies should strive to align their use of aviation with operational demands. However, risk aversion may lead agency administrators to over-contract for aviation resources to avoid public and political consequences that arise after destructive wildfire events. The question of contract structure is related to the question of optimal composition of the aircraft fleet addressed in a 2012 report by the Rand Corporation (Keating et al., 2012).

Economically efficient procurement requires an understanding of aviation effectiveness. The Aviation Firefighting Use and Effectiveness Report is an attempt to quantify effectiveness. However, its study design fails to objectively measure effectiveness. We propose a research design to quantify the effect of aviation drops on fire growth and intensity. The results of our proposed analysis can be used to quantify the benefits of aviation use and can inform firefighting strategy as well as operational needs for different resource types.

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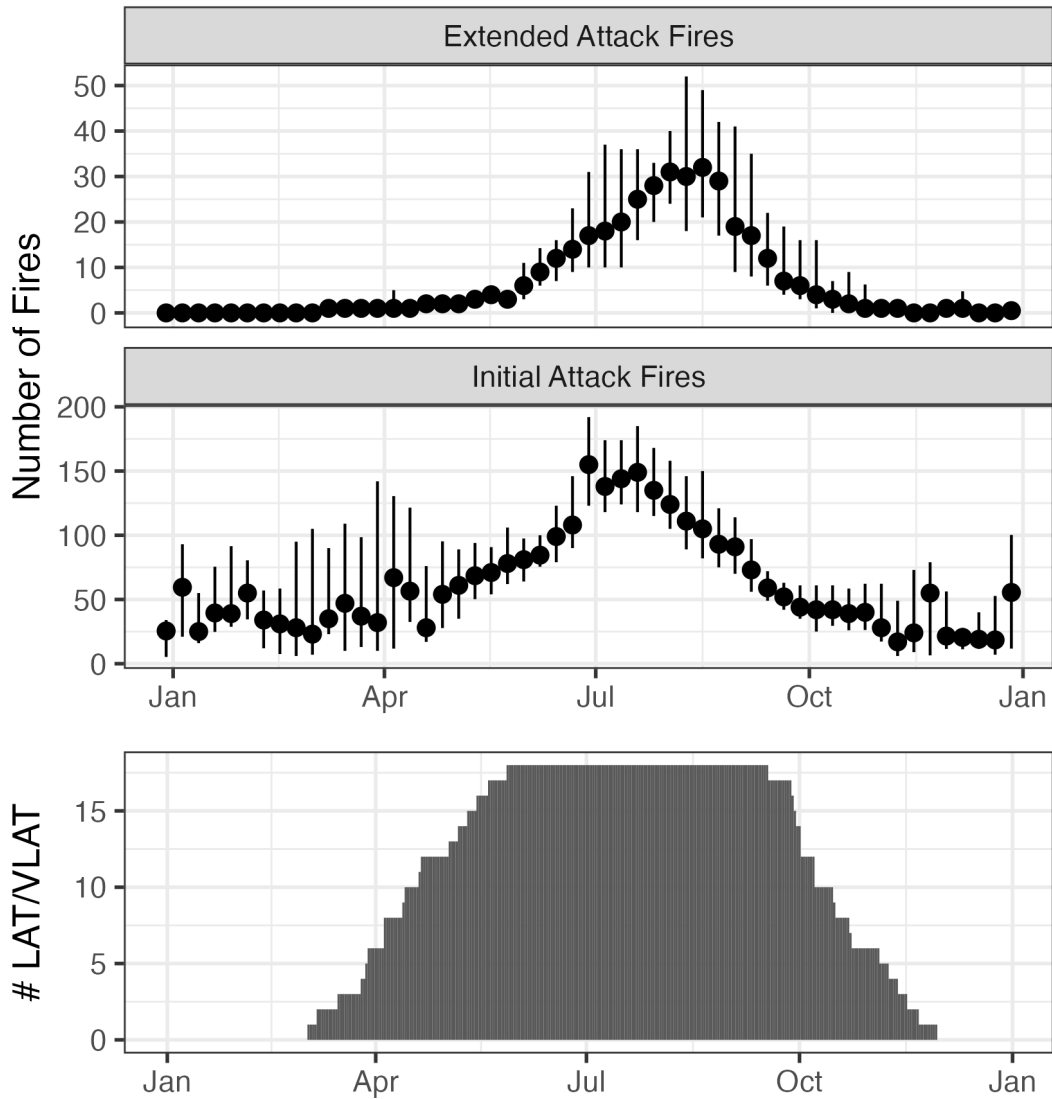


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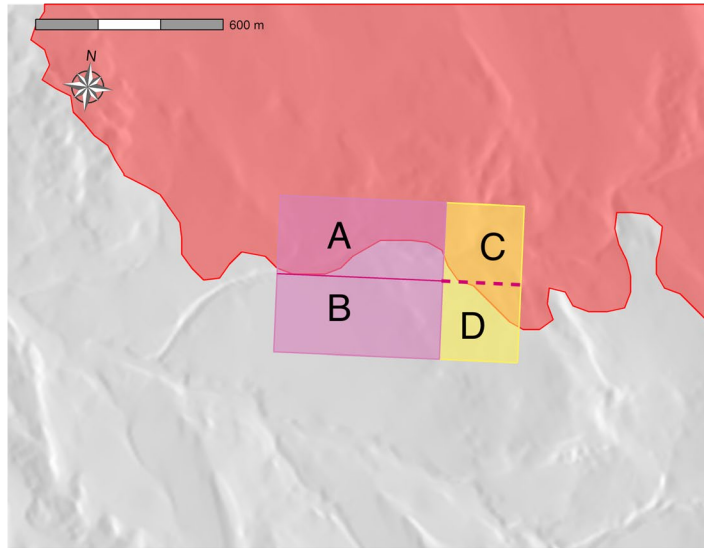
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**Figure 1:** Trends of Extended Attack (top) and Initial Attack (middle) fires from 2007 to 2021. The points represent the median and the lines represent the interquartile range (25th to 75th percentile). The bottom panel represents the number of Large Airtankers (LAT) and Very Large Airtankers (VLAT) available by day under exclusive use contract in 2022. The initial and extended attack fire counts are compiled from historical daily situation reports posted at <https://www.nifc.gov/nicc-files/sitreprt.pdf> and collected using code from (Nguyen, 2023), and the number of LATs and VLATs contracted are from the June 24, 2022, Schedule of Items posted at [https://www.fs.usda.gov/Internet/FSE\\_DOCUMENTS/fseprd1041508.pdf](https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd1041508.pdf)



*Figure 2: Retardant drop on the Terek Fire in Wyoming 2018. The fire (red area) is progressing south. The treated group is the magenta region, and the control group is in yellow. Regions A and C form the pre-area and B and D form the post.*