United States Department of Agriculture

Aerial Firefighting Use and Effectiveness (AFUE) Report

March 2020

Contents

Executive Summary

Background

In 2013, the U.S. Government Accountability Office (GAO) reviewed Agency efforts to determine an adequate firefighting aircraft fleet and found there was insufficient information on the performance and effectiveness of firefighting aircraft. In their report, GAO-13-684, they made three recommendations as follows:

1. Expand efforts to collect information on aircraft performance and effectiveness to include all types of firefighting aircraft in the federal fleet.
2. Enhance collaboration between the agencies and with stakeholders in the fire aviation community to help ensure that Agency efforts to identify the number and type of firefighting aircraft they need reflect the input of all stakeholders in the fire aviation community.
3. Subsequent to the completion of the first two recommendations, update the agency's strategy documents for providing a national firefighting aircraft fleet to include analysis based on information on aircraft performance and effectiveness and to reflect input from stakeholders throughout the fire aviation community.

AFUE's mission is: ***"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."***

This report describes project achievements, preliminary results, and opportunities for the U.S. Department of Agriculture, Forest Service, its partners, and its cooperators to strategically improve aerial and overall firefighting with empirical information addressing the three GAO recommendations. This update will acquaint the reader with the study design, data collection, preliminary results, opportunities and next steps and highlights of the AFUE study. The goal is to develop and implement performance measures, support evidence-based resource deployment decisions, and inform strategies for future aviation budgeting and contracting. This effort will enable the Agency to monitor, learn, and adapt to changing conditions and to ensure financial viability while also maintaining a high degree of operational effectiveness.

Guiding Principles

- **Performance and Effectiveness:** Collection and analysis of data, along with definition of evaluation criteria, were anchored into the objective to quantitatively document aircraft performance and effectiveness per GAO recommendations.

- **Risk Management:** AFUE supported best risk management practices, including generating best available information, supporting organizational learning, and summarizing performance in a dynamic and uncertain management context in terms of probability of success.

- **Transparency:** AFUE reports clearly identified study strengths and limitations, including potential sources of error and bias.

Significant Contributions & Key Findings

AFUE was conducted at a time of significant transition in the aviation program. It has been less than 10 years since the Forest Service began transitioning away from Korean War-era airtankers. During this time, we have completed a full transformation of our airtanker fleet and now exclusively operate next generation capable Airtankers. We have also modernized our helicopter fleet, resulting in generally better performance with more effective retardant and water delivery. Although not part of the AFUE study, we continue to modernize our aviation fleet by standing up the unmanned aircraft system program which will further enhance our overall agency capabilities.

The AFUE study provides a first-of-its-kind baseline information gathering and analysis effort regarding when and why aviation resources are utilized in responding to wildfires while evaluating mission completion performance. This information will be used to inform future analyses on operational use and fleet investment decisions.

AFUE developed a novel performance measurement framework identifying a range of drop objectives and evaluated success with respect to a range of possible outcomes. The AFUE team capitalized on decades of firefighting experience and incorporated feedback from the interagency steering committee to build this expert-based, operationally relevant framework. AFUE showed that aviation resources are used for a wide spectrum of response operations throughout the different stages of the wildfire life cycle. The AFUE performance framework enabled scalable analysis of individual drops or the ability to summarize results across multiple drops and sets of conditions by assigning a performance classification on the basis of alignment between objectives and outcomes.

AFUE developed two new performance metrics to summarize patterns of results: Interaction Percentage (IP) and Probability of Success (POS).

- **Interaction Percentage:** For a variety of reasons, not every drop interacts with a fire; AFUE only evaluated effectiveness for drops that did interact with fire. IP quantifies the proportion of drops that did interact with fire. Many drops provide utility and insurance by increasing line width or to anchor burnout operations, but do not end up visibly interacting with the fire. IP is computed as the number of drops with known outcomes that interacted with the main fire divided by the total number of drops with known outcomes.

- **Probability of Success:** POS is computed as number of effective drops divided by the total number of drops with known and interacting outcomes. This measure can be calculated for any set of conditions to see how success likelihood can vary with factors such as drop objectives, aircraft type, and fire type.

Using this framework as a guide for field data collection and analysis, AFUE identified patterns of aircraft use, performance and effectiveness that have not previously been documented. These quantifiable measures of objectives and outcomes – and how they vary across aircraft type – can be used as essential pieces of information supporting efficient fleet use and design. Key findings include:

- Common patterns in usage by fire type and drop objectives suggest the following grouping of aircraft: (1) helicopters and scoopers; (2) single engine airtankers (SEATs); and (3) large airtankers (LATs) and very large airtankers (VLATs). Given their ability to reload from water bodies, scoopers exhibit similar use characteristics to helicopters versus other airtankers. Although SEATs had a similar breakdown of drop objectives with LATs and VLATs, they were used more frequently for initial attack and entail widely different logistical considerations concerning response time, cruising speed, drop volume, etc.

- Across all drops from all aircraft, overall IP was 89% and POS was 0.82.

- Most drops occurred in large fires rather than initial or extended attack due to the duration, size, and values threatened during the lifecycle of those events, and the pattern was most pronounced for type 1 helicopters (74%), multiengine scoopers (74%), LATs (61%), and VLATs (65%).

- Delaying fire spread was a common objective for all aircraft, comprising 41% of all drop objectives; it was also a common outcome, comprising 36% of all drop outcomes.

- Reducing fire intensity was a common drop objective for helicopters and scoopers (32% to 48% of drops), and this tactic was largely effective at the drop scale (POS = 0.81-0.96).

- SEATs, LATs, and VLATs were rarely used to reduce fire intensity and instead used more for halting fire spread (41% to 45% of all drops); results indicate lower probabilities of success for these tactics (POS = 0.55 to 0.67).

- SEATs, LATs, and VLATs were used slightly more frequently than other aircraft to provide point protection of values (8% of drops). These drops had higher POS values compared to other airtanker drop objectives (POS = 0.78 to 0.87).

- SEATs, LATs, and VLATs had lower IP and POS values than helicopters and scoopers, related to their comparatively higher use for aerial line construction and halting fire spread. The IP and effectiveness of drops from these aircraft were very similar across aircraft types.

- Compared to helicopters, SEATs, LATs, VLATs, and scoopers had higher rates of unknown outcomes associated with no visual confirmation of the effect of the drop on achieving the objective.

Introduction

In 2012, the U.S. Department of Agriculture Forest Service initiated a multi-year Aerial Firefighting Use and Effectiveness (AFUE) study. The study's objective was 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." An interagency steering committee provided guidance to develop and implement performance measures, support evidence-based resource deployment decisions, and inform strategies for future aviation budgeting and contracting.

AFUE spent several years scoping, planning, and developing data collection methods. In 2014, the Forest Service, Fire and Aviation Management (FAM) program tasked the National Technology and Development Program (NTDP) to develop and apply performance metrics, technologies, and evaluation criteria that support effective strategic and tactical decisions. In 2015, the Fire Management Board signed a letter explaining the intent of the AFUE project and requested all incident commanders and duty officers grant AFUE access to all wildfire incidents nationwide for data collection. In that same year, under the NTDP organization, AFUE began field data collection with dedicated firefighters.

AFUE was a longitudinal study, and multiple years of data collection, quality assurance, and refinements support meaningful results. AFUE includes data from 2015-2018 at 272 incidents in 18 states spanning multiple jurisdictions and amounting to observations of 18,929 helicopter drops, 3,303 scooper drops, and 5,379 airtanker retardant drops. Each drop was analyzed on the basis of objectives and outcomes, and results were summarized according to evaluation criteria to quantify performance and effectiveness. AFUE also collected data summarizing aircraft use according to a number of variables including fire type (initial attack, extended attack, or large fire support), fuel type, weather conditions, and drop characteristics (e.g., time of day, aircraft speed), which will enable development of models to predict effectiveness and support decision making.

The AFUE study directly comports with recommendations from the U.S. Government Accountability Office report GAO-13-684 to collect information on aircraft performance and effectiveness, and to enhance collaboration between agencies and stakeholders in the fire aviation community. The significant expansion of the knowledge base on aircraft performance and effectiveness from the AFUE study should facilitate timely and informed updates to agency's' aviation strategy documents. Further, the AFUE study is consistent with recommendations from past Quadrennial Fire Reviews to improve performance measurement and inform strategic dialogues about firefighting resources.

Methodology

Data Collection Team

The data collection team consisted of four crews, or modules, of three to four single resource qualified firefighters, each with roughly 10 to 25 years of firefighting experience. Each module mapped aerial drop activity and recorded incident objectives, outcomes, and conditions for aerial suppression actions that supported tactical and strategic incident objectives. The module coordinator coordinated crew movements. Forest Service data collection teams also worked with aircraft vendors to ensure consistency in data collection methodologies. Additional details about the AFUE organizational chart, including roles for analysts, project and program leadership, and relationships to FAM can be made available from AFUE personnel.

Study Design and Sampling Plan

AFUE was a longitudinal study of non-random samples based on on-the-ground observations by AFUE personnel. AFUE sampled fires where firefighters used aircraft, particularly those where firefighters used airtankers. The target population was therefore aerial firefighting activity and not all wildland fires. Personnel needed to be able to walk around, drive around, or fly over drops to map and inspect them for drop pattern consistency, fuel type, and model, retardant shadowing, and other data. These factors led to a purposive sampling design with an intent to track and sample from all aircraft activity each year. The design was implemented because a random experiment was not possible, so the AFUE team selected fires for observation in a purposeful way to capture a range of uses and conditions such that results are more likely to be comprehensive and informative. AFUE surveyed targeted positions in the Federal fire aviation community to validate terminology and evaluation methods.

To increase the likelihood that sample observations would be representative of the target population, geographic variation was maximized by making observations in as many States, Geographic Area Coordination Centers (GACCs), and dispatch center areas as possible, paying close attention to areas that had less frequent active fire seasons. Further, AFUE personnel sampled from all fire management strategies, including full suppression, as well as confine and contain, and in rarer cases monitoring strategies. Every attempt was made to map incidents and drops covering a wide range of topography, vegetation and fuels, weather conditions, and fire behavior ranging from smoldering (fire burning without flames) and creeping (fire burning with a low flame and spreading slowly) to flanking (when a fire is spreading roughly parallel to the main direction of fire spread), running (fire spreading rapidly with a well-defined head), torching (burning of the foliage of a single tree or a small group of trees, from the bottom up), and crown fire (fire that advances from top to top of trees or shrubs more or less independent of a surface fire).

Field Data Collection

Data collection began by in-briefing incident commanders, followed by physical observations of as much activity as possible. Data quality assurance and quality control was an essential step, as was communicating with fire managers during and after fires to complete and append records. GIS data was collected with mobile devices. Assessing effectiveness required comparison of outcomes to the range of planned contributions. AFUE analysts classified outcomes into categories to generate performance metrics that can be broken down by many variables. Data dictionaries were developed to ensure standardized reporting of drop objectives and outcomes per these categories.

AFUE personnel applied analysis protocols to data collection from 2015 to 2018, at incident locations throughout the USA in 18 States and across all nine Forest Service regions. Incident commanders and duty officers generally granted AFUE access to wildfire incidents nationwide for data collection. Figure 1 shows where AFUE collected sample drops by lead response jurisdiction. Widespread access allowed AFUE to make observations of all aircraft types and configurations for incidents that occurred in varying terrain, fuel, weather, and fire conditions.

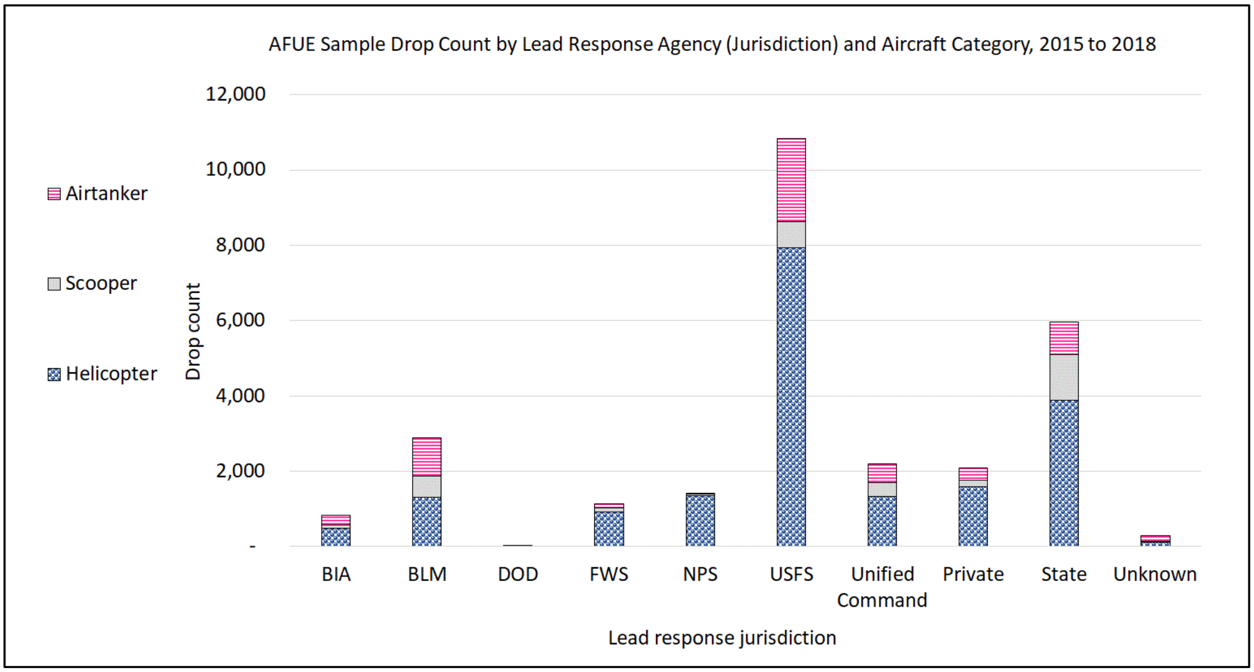


Figure 1—2015 to 2018 AFUE drop sample by lead response jurisdiction. Colors represent the number of observations by aircraft categories. Red represents fixed-wing retardant airtankers (all sizes). Gray represents fixed wing scoopers. Blue represents helicopters. Each fire season provides a different amount of sampling opportunity and intensity; this chart reflects the four-year composite. BIA—Bureau of Indian Affairs, BLM—Bureau of Land Management, DOD—Department of Defense, FWS—Fish Wildlife Service, NPS—National Park Service, USFS—U.S. Forest Service.

Data and Analysis Framework

The process of documenting use and recording objectives and outcomes was based on development of new terminology to classify and communicate aerial firefighting objectives and outcomes. It was also based on detailed observations across nested management scales (Figure 2). The most basic unit of analysis is a resource action, i.e., an individual drop from an aircraft. The next scale is a task, entailing one or more related resource actions that focus efforts toward achieving common operational and tactical objectives in a common area, during one shift or operational cycle. The logic for the multiple scales presumes not all drops need to be effective to reach desired incident outcomes. For the purposes of simplicity and clarity in this report, presentation of results is limited to drop objectives and outcomes.

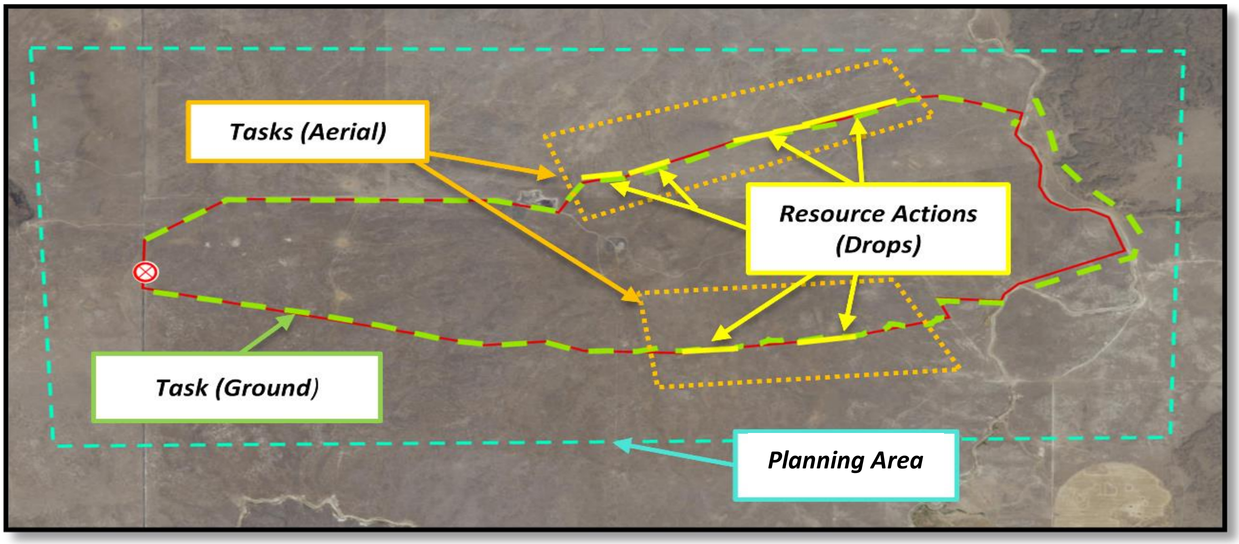


Figure 2 – A sample map showing the features of a fire and the scales for analyses. Yellow points and lines represent drops. Orange, dashed polygons delineate aerial tasks. Green lines and polygons delineate ground tasks. The blue-green polygon delineates the planning area. The red line delineates the final fire perimeter.

Development of evaluation criteria for objectives and outcomes capitalized on the AFUE team's collective decades of firefighting experience and incorporated feedback from the interagency steering committee. After preliminary observations and fact-finding discussions, it became clear that firefighters used aircraft for a much broader range of objectives than building containment lines (which was a common assumption in past studies). Based on observations and expert input, AFUE then defined a range of options for drop and task objectives (Table 1) and drop and task outcomes (Table 2). More detailed drop objective descriptions can be made available by AFUE personnel; here, drop objectives are shown by their more general task work assignments.

The general information and workflow for evaluating performance and effectiveness of aerial firefighting is shown in Figure 3. Cataloging observations provides a baseline understanding of patterns of use, and AFUE collected data on a range of additional attributes including geography, terrain, fuels, weather, drop characteristics, and ground resources, which further help contextualize findings. AFUE then recorded objectives and outcomes, and evaluated effectiveness based on the degree of alignment between the objective and the outcome. Finally, AFUE developed two key performance measures that summarize effectiveness in terms of how often aircraft make drops that interact with the fire and the probability of success for those drops that do interact.

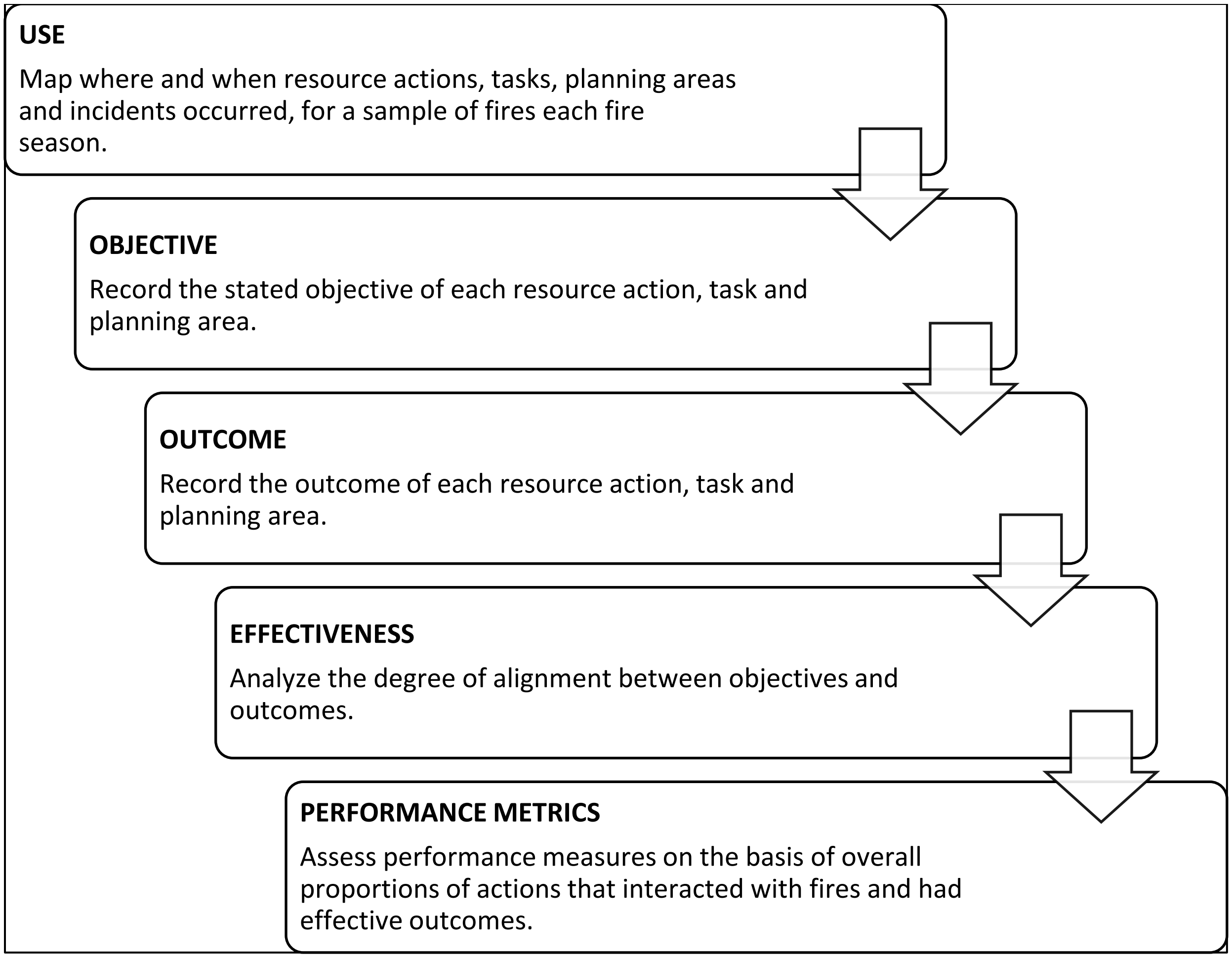


Figure 1 — AFUE's information and workflow for evaluating use, effectiveness, and performance measures.

Recording Drop Objectives and Outcomes

AFUE crews used air-to-ground channels and air-to-air radio frequencies to listen for drop requests and conversations among ground requestors, command and control, and dropping aircraft pilots. They occasionally gleaned information about air operations from incident management team planning meetings or operational briefings. Crews translated the local fire lingo (such as "check it up," "hold it on that ridge," "try to save that barn") and selected the best objective option from the list and description of drop objectives. If a drop occurred when crews were not able to listen, they later attempted to confer with individuals who made the request and guided the drop. Crews verified their selections with aerial command and control and/or ground fire personnel on scene when drops occurred and selected "unknown" when appropriate. Table 1 provides descriptions of drop objectives (grouped according to more general aerial task work assignments).

Table 1 — Descriptions of task work assignments. More detailed drop objectives are available from AFUE.

Drop objectives	Description
Reduce fire intensity/flame length	The intent of the drop(s) is to cool an area of fire activity. This may be needed so ground personnel can work closer to the fire activity (e.g., begin or continue to go direct). Examples include knocking down crown fire, torching, and preventing spotting, etc.
Delay fire spread/retard growth	The intent of the drop(s) is to delay the fire's rate of spread in the same location (head, heel, specific flank, spot, etc.) of the fire. Examples include buying time for ground resources to construct line or for evacuations.
Support ignition operations	The intent of the drop(s) is to support ignition operations. Examples include pretreating to reduce spotting potential, keeping fire in check to ensure implementation of preplanned ignition operation, or reducing growth potential in the event of spots to prevent escape, etc. This is the only work assignment that can include all drop-level objectives. Note this objective was used in 2015 and 2016. AFUE removed this objective as a domain option in 2017. AFUE recorded other objectives aircraft use to support ignition operation aerial tasks.
Point protection	The intent of the drop(s) is to protect a value(s) at risk (VAR). These drops should be within the immediate area of the VAR or be executed primarily to reduce the probability of fire reaching the VAR or to reduce damage to the VAR.
Line fire/halt advance	The intent of the drop(s) is to construct aerial line to halt fire spread. These drops are used to halt the spread of a section of the fire's edge before, during, or after ground engagement or without the aid of ground personnel.
Extinguish fire/spot fire	The intent of the drop(s) is to fully extinguish the entire portion of the fire or spot fires (generally a rare occasion, usually a small area, and likely a fine/flashy fuel).

AFUE crews personally observed the fire's interaction with the aerial drops and listened to radio traffic (including command, tactical channels, air-to-ground, and air-to-air victor radios) for information regarding how well drops achieved what they were intended to do (i.e., reduce fire intensity, delay fire spread, halt fire, protect points). Crews translated the local fire lingo (such as "it hung it up for long enough," "it held," "it skirted around those first three drops," and "it spotted right over that first drop") and selected the best option from the drop outcome domain list and data dictionary descriptions. When possible, crews verified their selections with ground fire personnel on scene when drops occurred or interacted with fire or with individuals who could observe drops from a distance. Table 10 provides descriptions of drop outcomes.

Table 2 — Descriptions of drop outcomes. More detailed outcomes are available from AFUE.

Drop outcomes	Description
Unknown/no data	The observer was unable to see the drop(s) outcome for a reason related to safety, access, smoke, fire behavior, etc. and could not acquire this information from any other source. Or, the observer knows the drop(s) interacted with the fire but does not know the outcome.
No fire interaction (NFI)	The drop(s) did not interact with wildfire or the drops were done to support ignition operations but did not interact with the main wildfire.
Burned through, spotted over, outflanked, change in tactics/priorities, failed to contribute	The drop(s) failed to contribute due to fire advancing past the drop(s) by burning across (through) the resource actions, by means of firebrand ignition, by burning around (outflanking) the end of the resource action, or the drops did not have a chance to contribute to broader task outcomes due to a change in tactics/priority.
Reduced fire intensity	The drop(s) successfully reduced fire intensity in the portion of the fire with which it interacted enough to contribute to successfully meeting planning area objectives without committing more resources.
Protected point(s) successfully	The drop(s) successfully prevented interaction or damage to the object of point protection (**Error! Reference source not found.**).
Delayed fire spread	Fire advanced past the drop(s), but the delay was enough to contribute to the successfully meeting planning area objectives without committing more resources.
Halted fire spread	The drop(s) successfully stopped the portion of the fire it interacted with from advancing.

Summarizing Aircraft Use and Effectiveness

AFUE data collection allows for summarization of aircraft use according to many variables. Primary variables reported here include:

- Aircraft type
    - Type 1, 2, and 3 helicopters
    - Single-engine and multi-engine scoopers
    - Fixed wing airtankers: single engine airtankers (SEATs), large airtankers (LATs), and very large airtankers (VLATs)
- Fire type, as recorded by AFUE observers and informed by common incident reporting requirements
    - Initial attack (IA): Aerial firefighters applied water, water enhancers, or long-term retardant with the initial responding resources only; and the fire was smaller than 100 acres in timber or 300 acres in grass/shrub.
    - Extended attack (EA): Additional ground resources supported the initial response, and the fire was smaller than 100 acres in timber or 300 acres in grass/shrub or when the fire duration exceeded 24 hours since engagement.
    - Large fire (LF): The fire was larger than 100 acres in timber or 300 acres in grass/shrub.
    - Unknown: Attempts to determine the fire type failed.
- Drop objective (see Table 1).

- Presence and engagement of ground resources (only for airtankers).

The most basic analysis of drop effectiveness considers drop objectives, drop outcomes, and the alignment between them. Analysis of outcomes according to the framework in Table 2 distills effectiveness into four categories: effective, ineffective, undetermined – no fire interaction, and undetermined – no visual confirmation. From this information, AFUE developed and implemented a new framework to assess the performance and effectiveness of aircraft in the operational fire environment, which is described in the next section. Drop outcomes and performance measures are summarized according to the same set of variables used to summarize aircraft use.

Performance Measures

AFUE developed a set of effectiveness measures to evaluate the effectiveness of aerial firefighting actions informed by risk and financial management principles, specifically the need to think in terms of possibilities and probabilities recognizing the complex and uncertain operational fire environment. Assessing the frequencies with which management actions have opportunities to change outcomes and their corresponding probabilities of success are essential components of performance measurements, for example in assessing fuel treatment encounter rates or amount of built fire line that engaged with fire. An intent of this study was to help build the evidence base around aircraft effectiveness to help fire managers monitor performance and assess probability of success.

It is important to note that performance evaluation presented here is agnostic as to why and how objectives were established, or what values were to be protected, and only evaluates performance and effectiveness in terms of meeting drop-level objectives – a necessary prerequisite to begin to quantify return on investment.

In light of this, AFUE created the following two performance measures:

- **Interaction Percentage (IP):** IP quantifies the proportion of drops that did interact with fire. AFUE only evaluated effectiveness for drops that did interact with fire. IP is computed as the number of drops with known outcomes that interacted with the main fire divided by the total number of drops with known outcomes.
- **Probability of Success (POS):** POS is computed as number of effective drops divided by the total number of drops with known and interacting outcomes. This measure can be calculated for any set of conditions to see how success likelihood can vary with factors such as drop objectives, aircraft type, and fire type.

Recognizing that it was not always possible to observe outcomes, AFUE also developed a process to account for uncertainty in effectiveness and performance evaluation. Specifically, AFUE developed “uncertainty bands” that indicate the range between the worst and best cases possible. For IP, uncertainty bands are quantified by assigning all unknown outcomes as no fire interaction (worst) or fire interaction (best). For POS, uncertainty bands are quantified by assigning all unknown – no visual confirmation outcomes as either ineffective (worst) or effective (best).). In addition, low interaction percentages and probabilities of success are likely to occur in some cases as part of incident risk management and Interaction percentages and probabilities of success of 100% are not feasible.

Limitations

A core element of the AFUE process is transparency, to clearly identify study limitations, including potential sources of error and bias. The study is not exhaustive nor is it a randomized experimental design, which limits inference; however, it is a first-of-its-kind observational study of aircraft use on wildfires which provides significant contributions to the overall knowledge base. Sampling adequacy is a known constraint, requiring several active fire seasons of collecting field data to obtain sufficient data for national-level reporting.

Bias and error could come from several sources. First, the sample may be biased towards incidents with substantial aircraft activity and especially those with any airtanker activity. Because AFUE was launched primarily to evaluate large and very large airtankers, choices were consistently made to observe fires with airtanker activity. Recognizing that many fires that receive any airtanker drops typically only receive a few drops, the sample could be underrepresenting fires with limited airtanker activity. Further, many aerial firefighting drops occur on remote fires that make direct observation challenging.

Second, the amount of activity can quickly exceed the capabilities of field crews to map and document everything, especially on larger fires. There are more unknowns for large fires than for small fires because it is much harder to comprehensively map activity over large areas. Third, many data records contain unknowns for some data fields, due primarily to safety reasons. It was especially difficult to observe drops interacting with fire while staying safely clear during high-intensity fire, which could lead to limited observations of drop effectiveness under extreme conditions. Fourth, time delays in arriving at drop locations to observe the fire interactions and confer with fire managers also introduced bias, especially for drops that were interior to the perimeter and made prior to arrival on scene. Fifth, mapping tended to be more complete during slower times of the year and with only four data collection modules it was difficult to capture high activity across geographic regions. Lastly, subjective manager interpretations and field observer inferences due to limited access or visibility issues also likely introduce bias and error.

Findings

Aircraft Use: Drop Summaries

Table 3 presents results of a sample summary for 27,611 drops that AFUE mapped across more than 270 incidents. Results are broken down according to aircraft category/type, including 18,929 drops from helicopters, 3,303 drops from scoopers, and 5,379 drops from fixed wing airtankers. In general, helicopters were used more than other types of aircraft, and type 1 helicopters in particular were used most.

Table 3 also summarizes sampling rate as a percentage of the estimated total number of drops to contextualize observation counts. Estimates for overall sampling rates were obtained by dividing the number of AFUE sample observations for each aircraft type by AFUE best estimates of the total target population each year (the federal estimate increased to reflect the estimated proportions of federal aircraft relative to all firefighting aircraft). Sampling rates vary across aircraft types, from a low of 2% for type 3 helicopters to a high of 13% for VLATs. Estimates for the single-engine scooper are considered a very rough estimate given access to only one year of Department of the Interior (DOI) records and no State records. Importantly, for the purposes of this report, characteristics were inferred from the sample to all Federal aircraft activity to describe broad trends and patterns of use and effectiveness.

AFUE observation data was used to summarize use characteristics according to a number of additional variables, including liquids dispensed, fire type, incident complexity, fuel types, location on fire, split loads, tactics, drop plan, command and control presence, ground engagement and top requestors. In coming sections this report will present some of these results.

Table 3 — Summary table of AFUE sample use results, by aircraft type, 2015 to 2018.

Aircraft category/type	Sampling	
	Drops observed	Estimated sampling rate (%)
Helicopter— type 3	3,028	2
Helicopter— type 2	5,771	3
Helicopter— type 1	10,130	5
Single-engine Scooper	1,626	7
Multiengine Scooper	1,677	7
Airtanker— SEAT	2,076	7
Airtanker— LAT	2,812	9
Airtanker— VLAT	491	13

Aircraft Use: Drop Objectives

Figure 4 shows the mission profiles (distribution of drop objectives) for the various aircraft types. Notice the similarities between helicopter and scooper mission profiles and differences between helicopter/scooper and fixed wing airtanker mission profiles. Delaying fire spread was a common objective for all aircraft, accounting for 40% of all drops. Otherwise, helicopters and scoopers were used more for reducing intensity (from 32% for type 1 helicopters to 49% for type 3 helicopters), and airtankers were used more for halting fire spread (from 42% for SEATs to 47% for VLATs). Extinguishing fire was an uncommon objective, typically 3% of drops or less, with the exception of Type 3 helicopters (17%) and multiengine scoopers (9%).

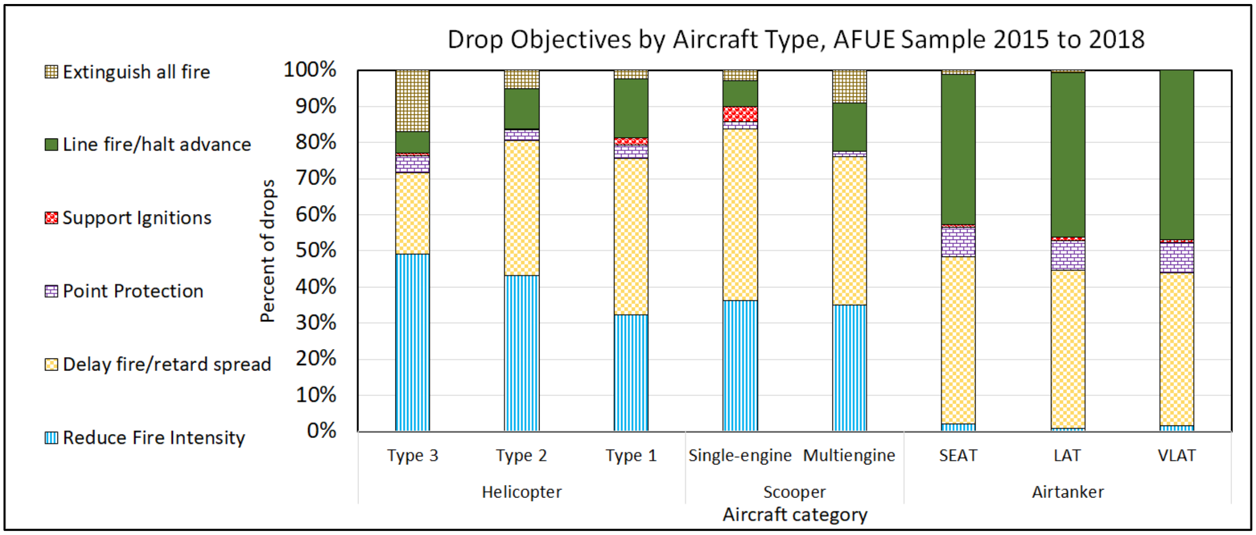


Figure 4 — AFUE sample drop objective results by aircraft type, 2015 to 2018. Ignition support only includes drops labeled that way in 2015 and 2016 but does not include drops done with variety of other drop objectives to support ignition operations in 2017 and 2018.

Aircraft Use: Fire Types

Figure 5 summarizes aircraft use by fire type (initial attack, extended attack, large fire, and unknown). In general, most sample drops occurred on large fires, which is largely consistent with earlier findings based on analysis of flight and fire records rather than drop observations. This is expected as large fires are longer in duration than short duration fires, allowing for more time available for drops to occur. Only one type of aircraft, the single-engine scooper, had a majority of drops for initial attack (51%). Conversely, five types of aircraft had a majority of drops for large fire: type 2 helicopter (57%), type 1 helicopter (74%), multiengine scooper (74%), LAT (61%), and VLAT (65%). Firefighters generally used smaller aircraft types within each category (type 3 helicopters, single-engine scoopers, and single-engine airtankers—SEATs) more in initial attack and used larger aircraft types within each category (type 1 and 2 helicopters, multiengine scoopers, LATs and VLATs) more for large fire.

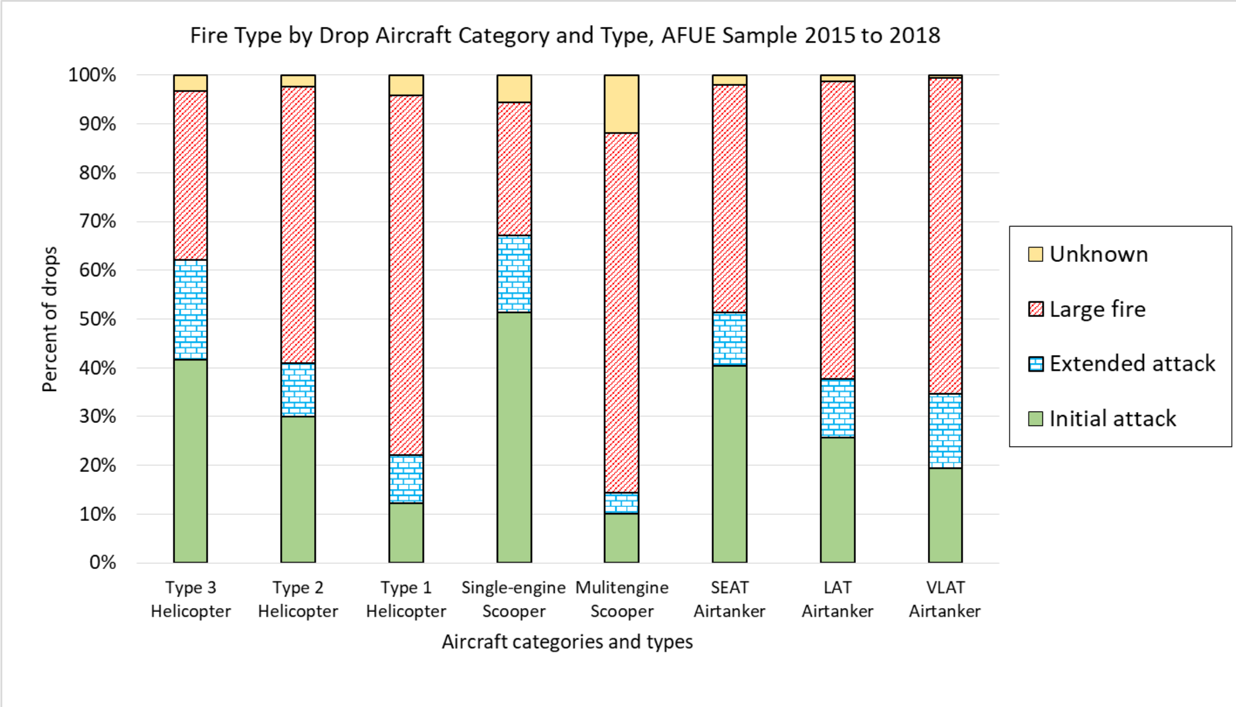


Figure 5 — Percentage of drops by aircraft category and type in each fire type as recorded by incident size at the start of each planning area observation.

Aircraft Use: Drop Objectives and Fire Types

Figures 6-8 show the mission profile patterns of the different aircraft categories by fire type (see Figure 5), in effect further deconstructing the results from Figure 4 and Figure 5. Some patterns in drop objectives across aircraft categories remain consistent, for instance the common objective of delaying fire spread, a heavier emphasis on reducing intensity for helicopters and scoopers, and a heavier emphasis on halting fire spread for airtankers. However, the relative proportions of these objectives differ across fire types. Notably, as the fire type progresses from initial attack to large fire: (1) for helicopters and scoopers, the percentage of drops for reducing intensity generally decreases and the percentage of drops for delaying spread generally increases; (2) for airtankers, the percentage of drops for delaying spread generally decreases and the percentage of drops for halting fire spread generally increases; and (3) across all aircraft the percentage of drops for ignition support generally increases. Mission profiles across fire types were generally more stable across airtankers, and more variable across scoopers. Because mission profiles for extended attack were more variable and it was the least common fire type for all aircraft (Figure 5), presentation of results focuses primarily on comparing drop objectives for initial attack and large fire.

Trends are apparent in mission profiles of aircraft types within categories by fire type. Firefighters used type 3 helicopters more for lining fire/halting advance and less for delaying fire/retarding spread in IA than in large fire. The mission profile of single-engine scoopers was like the mission profiles of helicopters in all fire types. The mission profile of multiengine scoopers was like the mission profiles of helicopters in IA but was more like the mission profile of airtankers in EA and somewhat like airtankers in large fire. The mission profile of multiengine scoopers was different than mission profiles of all other aircraft in EA. SEAT, LAT, and VLAT mission profiles were very similar across fire types, with greater use for delaying spread in IA and greater use for lining fire/halting advance in large fire.

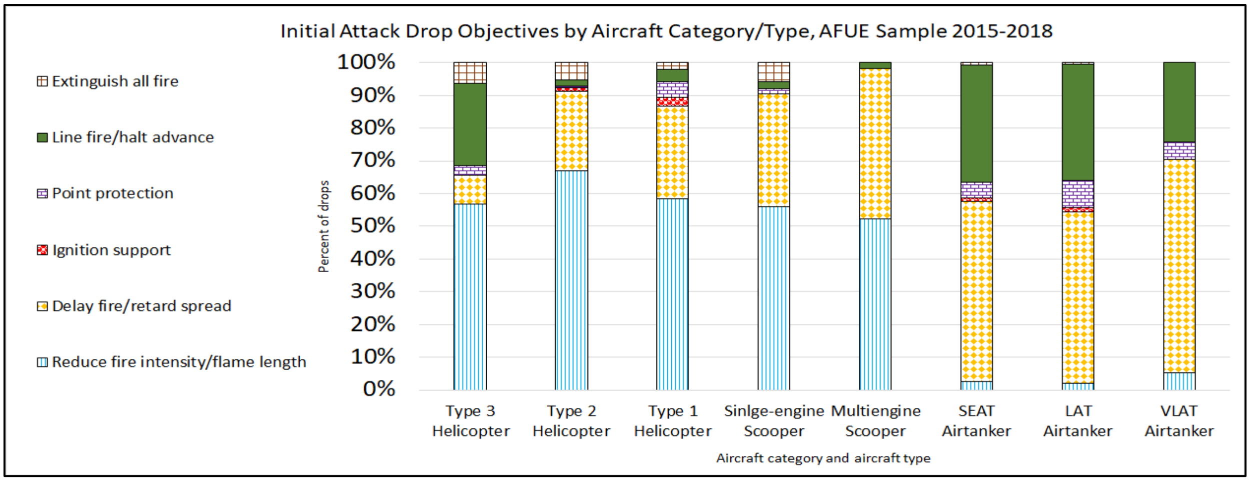


Figure 6 — Percentage of drops for different groups of drop objectives by aircraft category and type in initial attack -aerial firefighters applied water, water enhancers, or long-term retardant with the initial responding resources only; and the fire was smaller than 100 acres in timber or 300 acres in grass/shrub.

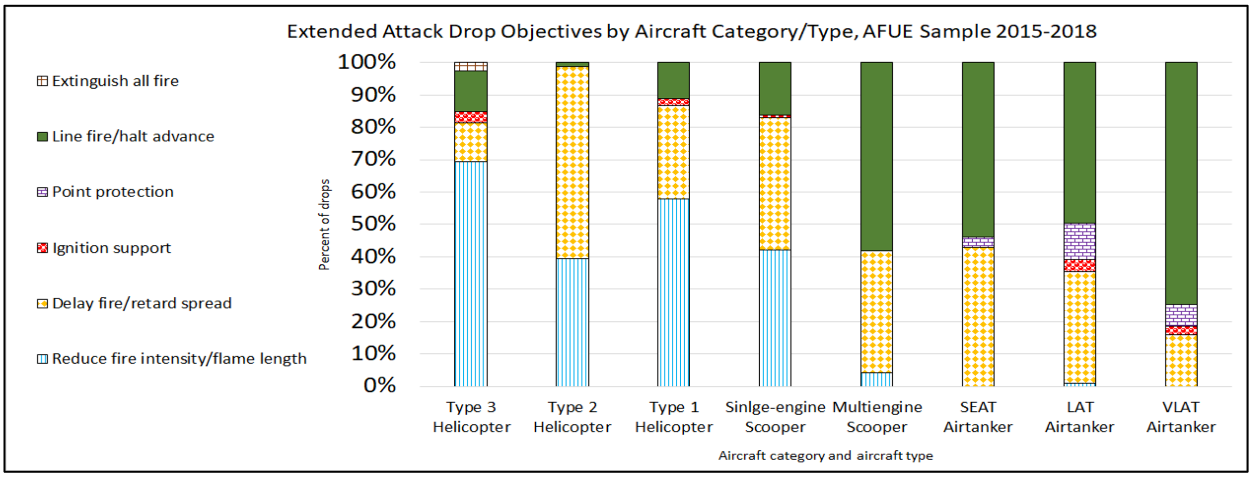


Figure 7 — Percentage of drops for different groups of drop objectives by aircraft category and type in extended attack—additional ground resources supported the initial response, and the fire was smaller than 100 acres in timber or 300 acres in grass/shrub or when the fire duration exceeded 24 hours since engagement.

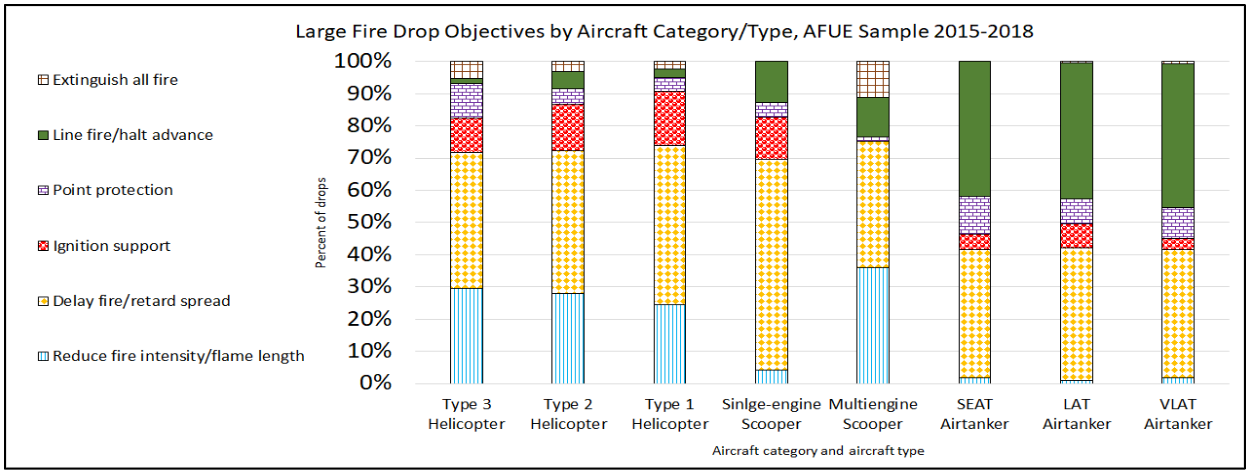


Figure 8 — Percentage of drops for different groups of drop objectives by aircraft category and type in large fire. Large fire (LF)—the fire was larger than 100 acres in timber or 300 acres in grass/shrub.

Aircraft Use: Drop Objectives by Ground Engagement (Airtanker only)

Figure 9 shows mission profiles specifically for airtankers, broken down according to the presence or some level of engagement by ground resources (crews, equipment, engines, or firefighters at large). Excluding drops with unknown drop objectives, 84% of observed airtanker drops were with ground engagement ("yes" bin), 11% without ("not at all-not mapped" bin), and 5% where the presence or degree of engagement of ground resources was unknown ("unknown-not mapped" bin). It is clear the mission profiles are different across these bins. For drops with ground engagement, the highest percentage of drops was to delay fire/retard spread (47%), followed by halting fire advance (39%). In other circumstances, the predominant drop objective tends to be halting fire advance (from 45% for "not at all" to 78% for "unknown"). Point protection percentages were generally comparable for "yes" and "unknown" (7%), increasing to 17% for "not at all." Not surprisingly, ignition support (5%) was only an objective with ground engagement.

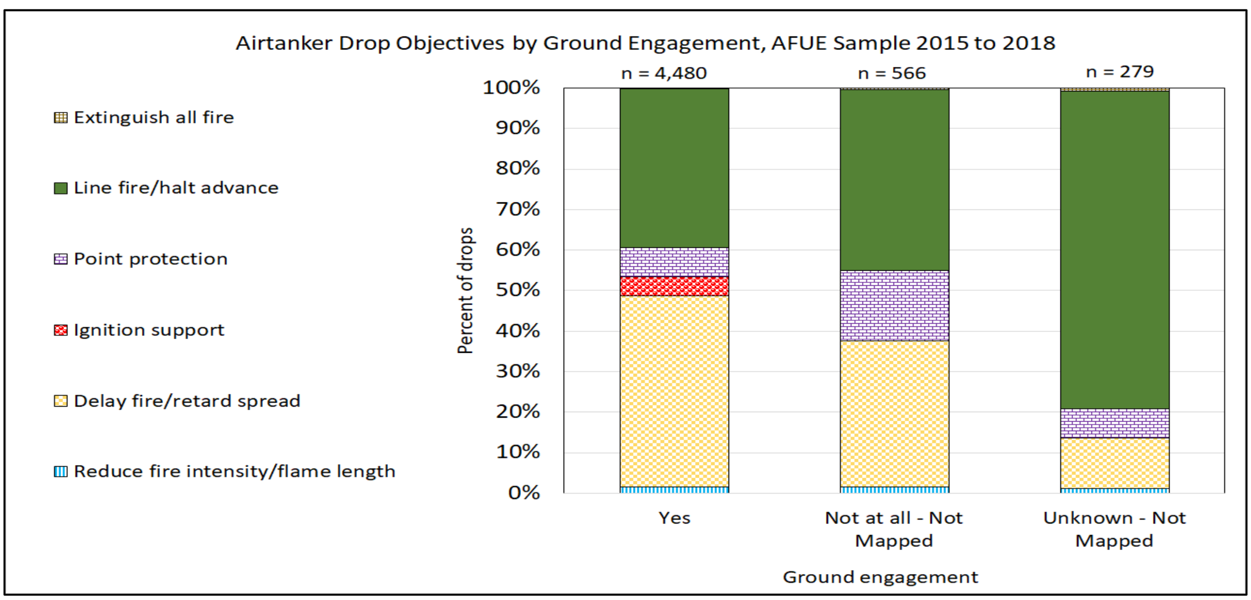


Figure 9 — Percentage of all airtanker retardant drops by drop objective with and without ground engagement. Ignition support includes drops labeled in 2015 and 2016 that way and which were done with variety of other drop objectives to support ignition operations in 2017 and 2018.

Aircraft Effectiveness: Drop Outcomes

Error! Reference source not found. shows the range of drop outcomes for the various aircraft types. Patterns are generally consistent with distribution of drop objectives (Figure 4). Delayed fire spread was a common outcome for all aircraft (from 26% for type 3 helicopters to 51% for single-engine scoopers). A higher percentage of helicopter and scooper drops reduced fire intensity than airtanker drops (from 29% for type 1 helicopters to 41% for type 2 helicopters), and a higher percentage of airtanker drops halted fire spread (from 16% for LATs to 23% for SEATs). The percentages of not effective drops were generally highest for airtankers (14%-17%), with burned through line and outflanked line the most common failure mechanisms for airtanker drops (additional details on failure mechanisms can be made available from AFUE personnel). Type 3 helicopters had the next highest percentage of not effective drops (12%), typically due to fire spotting outside the line. Accounting for the higher number of drops and generally greater effectiveness associated with type 1 and 2 helicopters, the overall percentage of not effective drops reduces to 7%. A sizeable percentage (16%) of all drops had no fire interactions or unknown outcomes, which was most prominent for airtankers.

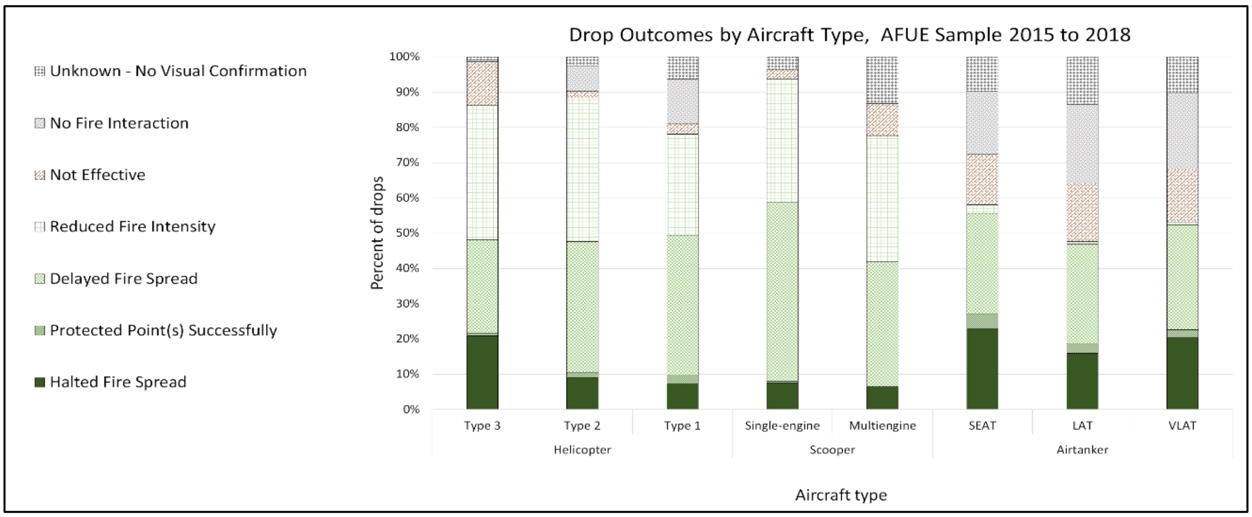


Figure 10 — AFUE sample outcomes by aircraft type, 2015 to 2018. The shades of green represent positive contributions and red represents different reasons for failure (burned through the line, outflanked, spotted outside the line, failed to contribute-unknown reason, change in tactics/priority, jettison).

Aircraft Effectiveness: Alignment of Objectives and Outcomes

Figure shows the drop effectiveness of various aircraft types on the basis of alignment of observed outcome with stated drop objective. The percentage of no fire interactions and drops with unknown outcomes are shown as well. In general, helicopters and scoopers had higher percentages of effective drops (from 62% for multiengine scoopers to 87% for single-engine scoopers) relative to airtankers (from 43% for LATs to 54% for SEATs). It is important to note also that airtankers had the greatest percentage of drops in “undetermined” categories, which affect effectiveness ratings. In the next sub-sections these numbers are analyzed in more detail describing the two key performance measures: interaction percentage and probability of success.

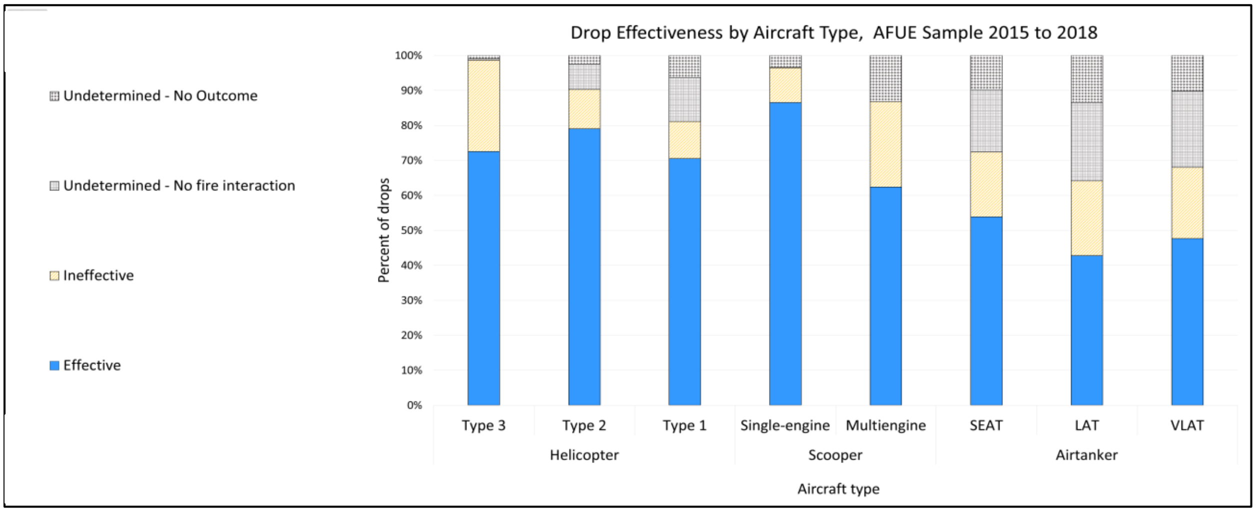


Figure 11 — AFUE sample effectiveness by aircraft, 2015 to 2018.

Aircraft Effectiveness: Drop Interaction Percentages (IP)

Figure 12 displays the drop interaction percentages (IPs) by aircraft type. Approximately 89% of all drops interacted with a fire (right-most column), although this was variable across aircraft types. Type 3 helicopters and both types of scoopers had IPs of approximately 100%, reflecting primary use for direct tactics. IPs were slightly less for type 2 (93%) and type 1 (87%) helicopters, and even less for airtankers (80% for SEATs, 74% for LATs, and 76% for VLATs), reflecting comparatively higher use for indirect tactics.

Also shown in Figure 12 are uncertainty bands that account for drops with undetermined outcomes. The upper bound assumes all undetermined drops interacted with the main wildfire, defined as drops made on the interior to the perimeter, point protection for example - (best case), and the lower bound assumes none of the undetermined drops interacted with the main wildfire (worst case). The bands are intended to convey the degree of uncertainty in the data without relying on any statistical assumptions about the distributions of the data. The greater the difference between the upper bound and lower bound, the greater the uncertainty around the true IP. The uncertainty around IP is greatest for multiengine scoopers due to that aircraft type having the greatest percentage of undetermined outcomes (Figure 11).

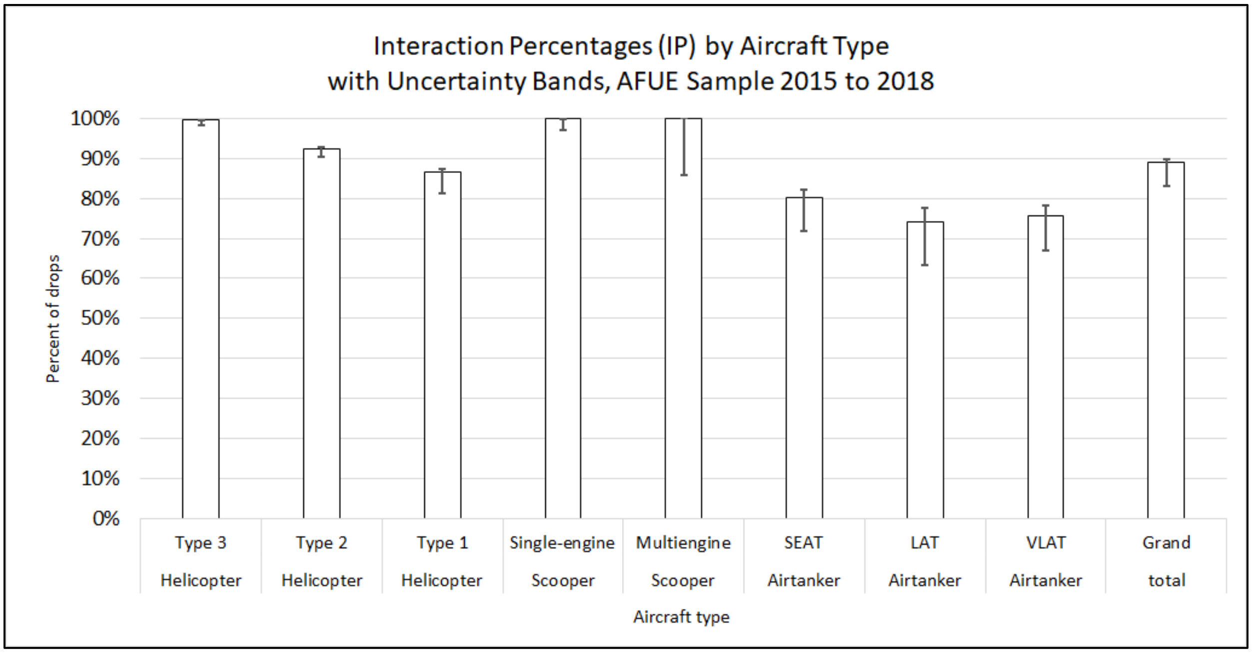


Figure 12 — AFUE sample interaction percentage (IP) results by aircraft, 2015 to 2018. The IP for each aircraft is the result of dividing the sample counts of interacting drops by total of interacting (effective plus ineffective) plus those with no fire interaction, in other words the proportion of drops interacting with the main fire to all drops with known outcomes. Bands indicate the range between the worst and best cases possible, assigning all unknown outcomes as no fire interaction or fire interaction.

Aircraft Effectiveness: Drop Probabilities of Success (POS)

Figure 13 shows the probability of success (POS) decimal values by aircraft type. POS values are only calculated for drops that had interactions with fires. Approximately 0.82 of all interacting drops with known outcomes were deemed successful, although values were variable across aircraft types. POS values were generally higher for helicopters (0.74 to 0.88) and scoopers (0.72 to 0.90) than airtankers (0.67 to 0.74). As with IP values, differences in POS partially reflect differences in mission profiles and usage by fire type. Uncertainty bands indicate that the largest difference between best and worst case is for airtankers; in the best-case POS values are approximately 0.80 and in the worst case as low as 0.43.

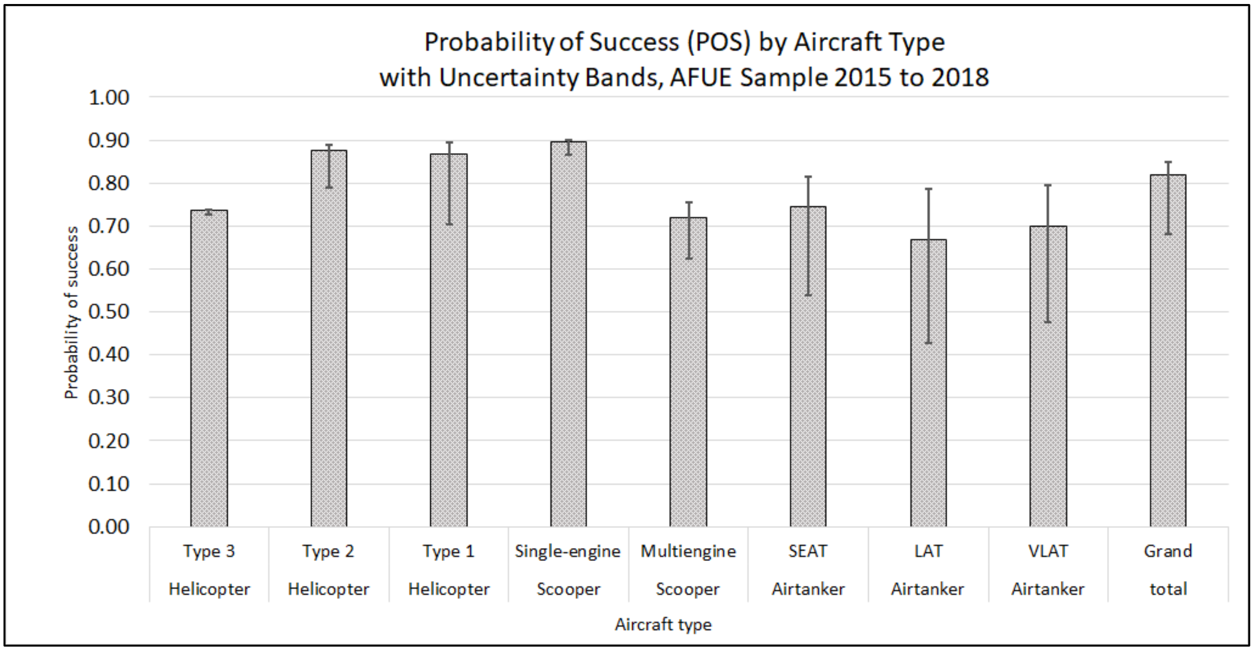


Figure 13 — AFUE sample probability of success (POS) results by aircraft, 2015 to 2018. The POS for each aircraft is the result of dividing the sample counts of effective drops by the total of effective plus ineffective drops, in other words the proportion of effective to all interacting drops. Bands indicate the range between the worst and best cases possible, assigning all unknown outcomes as either ineffective or effective.

Aircraft Effectiveness: Drop POS by Drop Objectives

While the POS calculations for each aircraft type shown in Figure 13 are informative, they do not account for the range of missions that aircraft perform. Figures 14-16 break down POS by aircraft type and specific drop objectives. First, Figure 14 addresses helicopter POS by drop objective; across all drop objectives and helicopter types the POS is 0.85. Referring to Figure 4, helicopters are generally used most to reduce fire intensity and delay fire spread, and POS values for these drop objectives are generally between 0.80-0.90. The exception is type 3 helicopters with the objective of delaying fire spread, with a POS of 0.68.

Type 3 helicopters had higher probabilities of success at reducing fire intensity/flame length and lining fire/halting advance (normally on small fires), but they were less effective at point protection. Type 2 helicopters were effective at reducing fire intensity/flame length, delaying fire/retarding spread, lining fire/halting advance, and extinguishing fire, but they were less effective at point protection. Type 1 helicopters were more effective than the other helicopter types at point protection and were effective at reducing fire intensity/flame length and delaying fire/retarding spread, but they were less effective at lining fire/halting advance (normally on large fires) or extinguishing fire. All helicopter types were effective at ignition support.

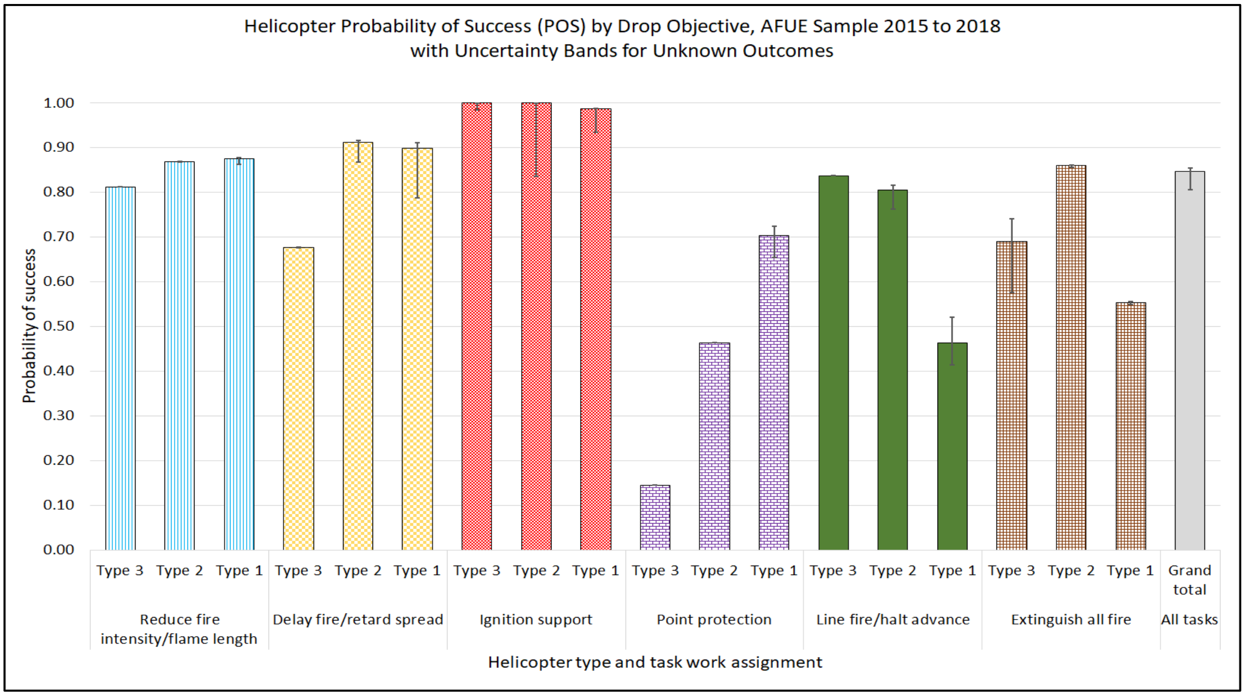


Figure 14 — AFUE sample probability of success (POS) results by helicopter type, 2015 to 2018. The POS for each aircraft is the result of dividing the sample counts of effective drops by the total of effective plus ineffective drops, in other words the proportion of effective to all interacting drops. Bands indicate the range between the worst and best cases possible, assigning all unknown outcomes as either ineffective or effective.

Figure 15 addresses scooper POS by drop objective; across all drop objectives and scooper types the POS is 0.81. Recall that mission profiles for scoopers are generally consistent with helicopters, and POS results here are qualitatively similar to those presented in Figure 14. Single-engine scoopers had higher POS values for reducing fire intensity/flame length (0.96), delaying fire/retarding spread (0.94), ignition support (1.00), and extinguishing all fire in the area (1.00), but they were not very effective at point protection (0.42). Multiengine scoopers were effective at reducing fire intensity/flame length (0.89) and delaying fire/retarding spread (0.83), but they were not effective at point protection with any of the 15 drops observed. Neither of the scooper types were effective at lining fire/halting advance.

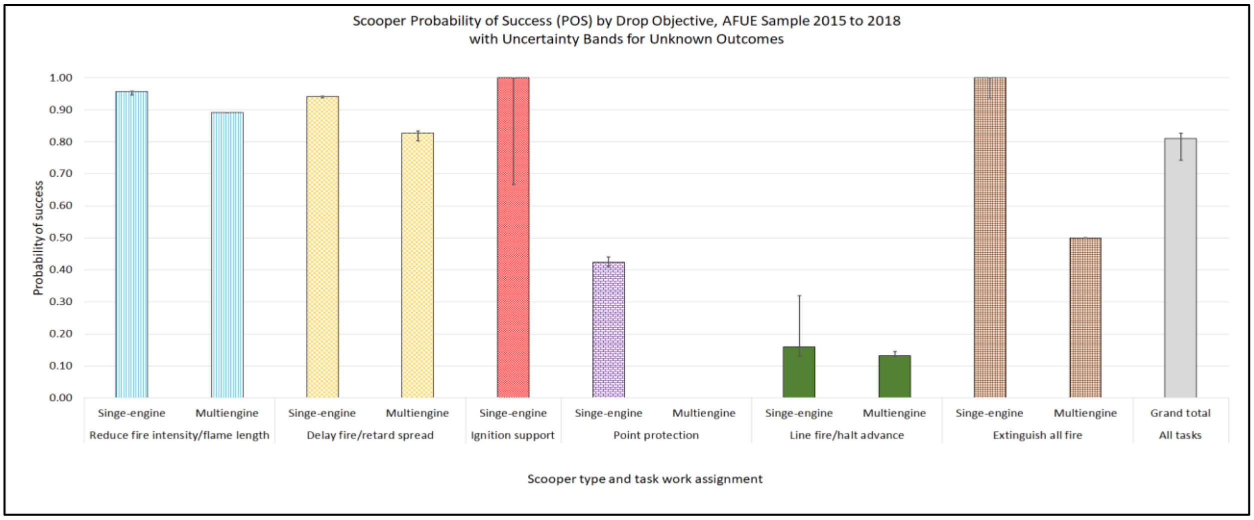


Figure 15 — AFUE sample probability of success (POS) results by scooper type, 2015 to 2018. The POS for each aircraft is the result of dividing the sample counts of effective drops by the total of effective plus ineffective drops, in other words the proportion of effective to all interacting drops. Bands indicate the range between the worst and best cases possible, assigning all unknown outcomes as either ineffective or effective.

Figure 16 addresses airtanker POS by drop objective; across all drop objectives and airtanker types the POS is 0.70. The patterns in Figure 16 are discernibly different from those in Figures 14 and 15. POS values or reducing fire spread are much lower, but these drop objectives comprise a very small proportion of the overall mission profile for airtankers (Figure 4). Instead, airtankers were generally more used for, and more successful at, delaying fire spread, halting fire spread, and point protection. SEATs had higher POS values for delaying fire/retarding spread (0.80), point protection (0.87), and lining fire/halting advance (0.67), but they were less effective at reducing fire intensity (0.43). LATs were effective at reducing fire intensity/flame length (0.69), delaying fire/retarding spread (0.75), and point protection (0.78) but they were less effective at lining fire/halting advance (0.55). VLATs were effective at delaying fire/retarding spread (0.80) and point protection (0.83) and were somewhat effective at lining fire/halting advance (0.62). There were not enough observations of VLAT use for reducing fire intensity/flame length or extinguishing all fire in the area to identify any clear patterns of effectiveness. Airtanker assignments to extinguish active fire were rare, and the number of airtankers extinguishing fires, regardless of size, was too few to identify any clear patterns. Large airtankers were not effective at ignition support, and there were no observations of SEATs or LATs supporting ignition operations.

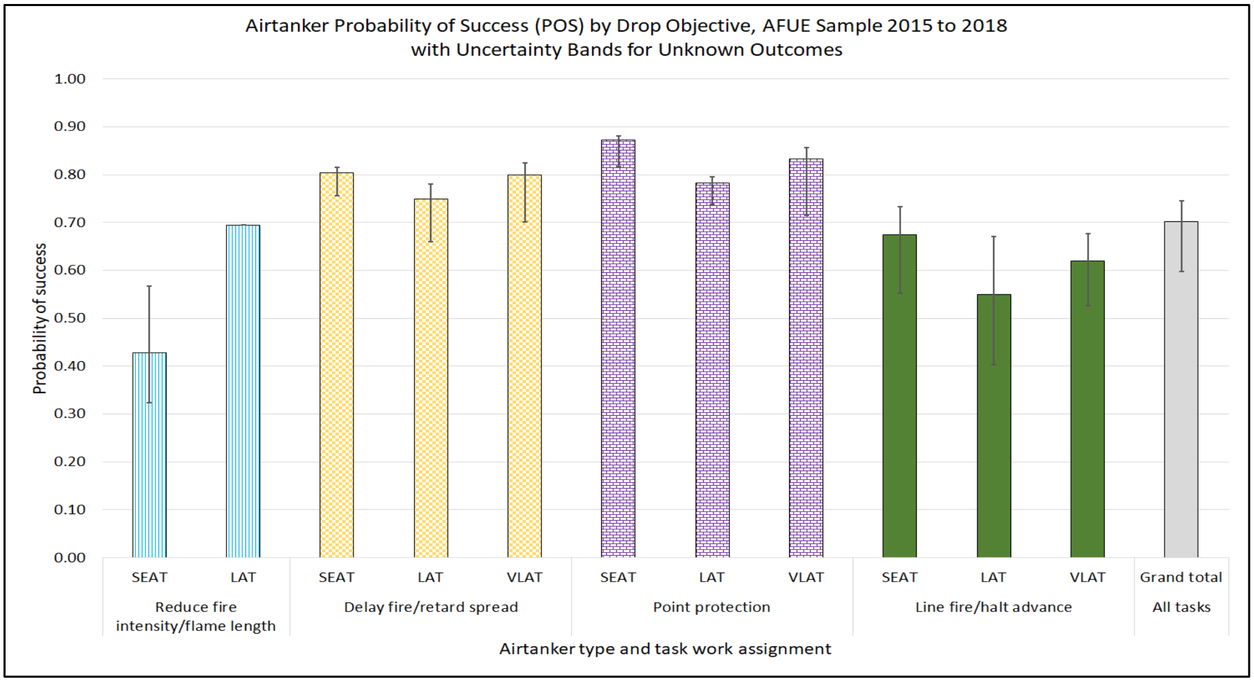


Figure 16 — AFUE sample probability of success (POS) results by airtanker type, 2015 to 2018. The POS for each aircraft is the result of dividing the sample counts of effective drops by the total of effective plus ineffective drops, in other words the proportion of effective to all interacting drops. Bands indicate the range between the worst and best cases possible, assigning all unknown outcomes as either ineffective or effective.

Aircraft Effectiveness: Drop IP and POS by Fire Types

Figures 17-19 summarize IP and POS values for aircraft by fire types and can be referenced against Figures 6-8 to see differences in mission profiles. Note the rightmost column in all three figures summarizes results across all drops, all aircraft types, and all fire types. First, Figure 17 summarizes these performance measures for initial attack. IPs were generally high in IA for all aircraft (79%-100%), but particularly high for helicopters and scoopers. A similar pattern emerged for POS, where values were higher for helicopters and scoopers (0.86 to 0.98) and lower for airtankers (0.65 to 0.81). Across all aircraft types, IP during IA was 95%, and POS was 0.90.

Figure 18 summarizes IP and POS for extended attack; across all aircraft these values during EA were 96% and 0.79, respectively. Performance for scoopers and airtankers appears generally poor during EA (IP as low as 0.69 for VLATs; POS as low as 0.38 for multiengine scoopers). However, EA comprises a small share of the overall workload of these aircraft (Figure 5) and the total number of drops from these aircraft is less than from helicopters (Table 3). Thus, overall performance in EA is generally high due to the comparatively better performance of helicopters that comprise approximately 70% of all observed EA drops.

Figure 19 summarizes IP and POS for large fire; across all aircraft these values during large fire were 85% and 0.79, respectively. POS for helicopters in large fire is generally lower than in IA or EA, most noticeably for type 3 helicopters (54%). One explanation is their small drop volume relative to the extent of large fires. POS for scoopers in large fire (0.70 to 0.84) is lower than for IA but higher than EA. POS for airtankers in large fire (0.70 to 0.73) is higher than IA (except SEATs) and higher than EA.

In general, IPs were lower for airtankers than other aircraft across all fire types. This was in part because of a higher percentage of indirect and contingency drops for airtanker operations compared to helicopter or scooper operations. IPs for SEATs and LATs were similar across fire types, and the highest IP for

VLATs was in IA. Type 2 and type 1 helicopters had lower IPs in LF than in other fire types. These results are not surprising given that firefighters used helicopters more for ignition support (burnout or backfire) in LF than in other fire types.

Perhaps the most interesting of these results is the lower POS for most aircraft types in EA—the brief period between IA and LF—when firefighters used aircraft more for lining fire/halting advance (according to AFUE sample mission profiles). The higher degree of difficulty associated with lining fire/halting advance relative to other work assignments partially explains some of the differences in POS, but other factors that correlate with different fire types are also likely contributors. For example, EA fires (by definition) have surpassed IA criteria and therefore often present more challenging fire behavior and suppression conditions.

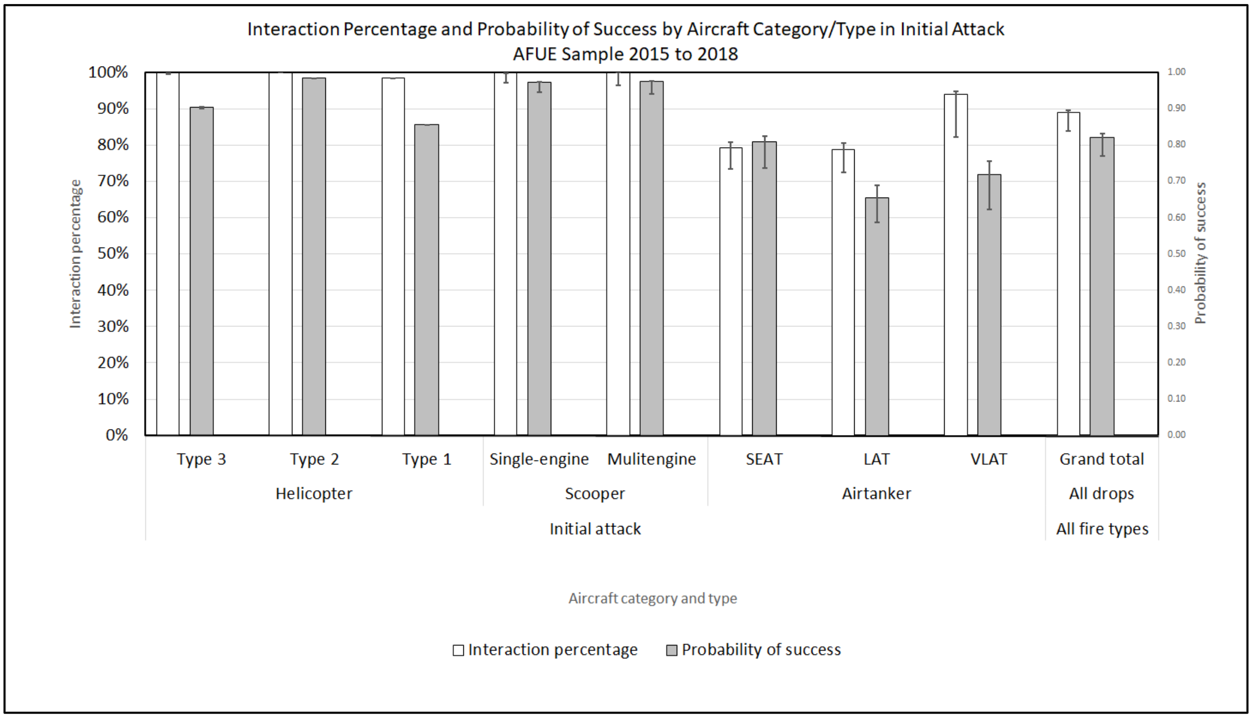


Figure 17 — AFUE sample interaction percentage (IP) and probability of success (POS) results by aircraft in initial attack, 2015 to 2018. The IP for each aircraft is the result of dividing the sample counts of interacting drops by total of interacting (effective plus ineffective) plus those with no fire interaction, in other words the proportion of drops interacting with the main fire to all drops with known outcomes. Bands indicate the range between the worst and best cases possible, assigning all unknown outcomes as no fire interacting or fire interaction. The POS for each aircraft is the result of dividing the sample counts of effective drops by the total of effective plus ineffective drops, in other words the proportion of effective to all interacting drops. Bands indicate the range between the worst and best cases possible, assigning all unknown outcomes as either ineffective or effective.

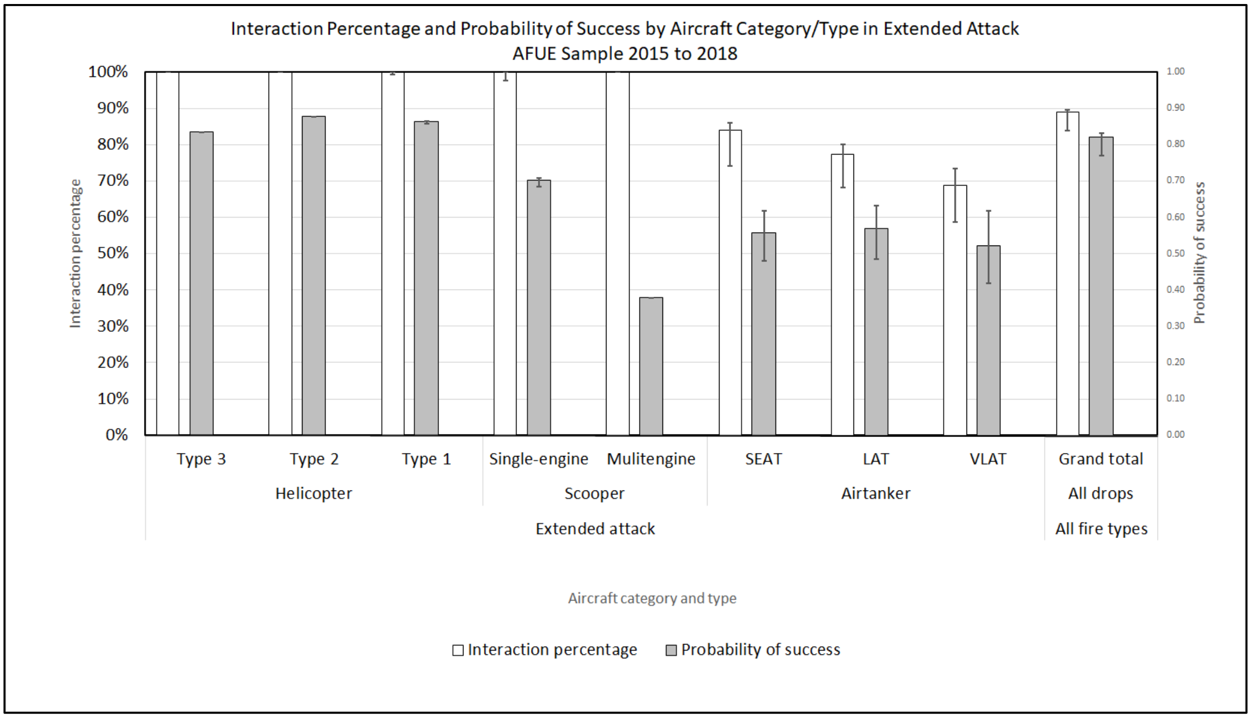


Figure 18 — AFUE sample interaction percentage (IP) and probability of success (POS) results by aircraft in extended attack, 2015 to 2018. The IP for each aircraft is the result of dividing the sample counts of interacting drops by total of interacting (effective plus ineffective) plus those with no fire interaction, in other words the proportion of drops interacting with the main fire to all drops with known outcomes. Bands indicate the range between the worst and best cases possible, assigning all unknown outcomes as no fire interacting or fire interaction. The POS for each aircraft is the result of dividing the sample counts of effective drops by the total of effective plus ineffective drops, in other words the proportion of effective to all interacting drops. Bands indicate the range between the worst and best cases possible, assigning all unknown outcomes as either ineffective or effective.

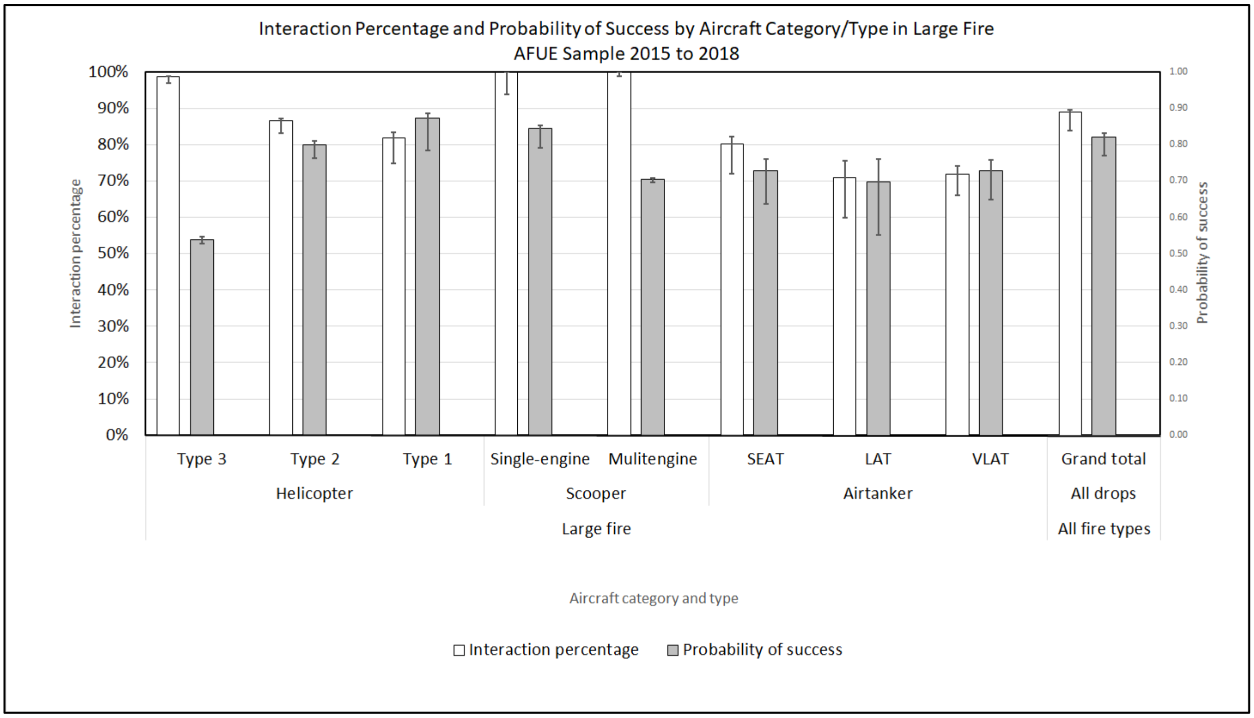


Figure 19 — AFUE sample interaction percentage (IP) and probability of success (POS) results by aircraft in large fire, 2015 to 2018. The IP for each aircraft is the result of dividing the sample counts of interacting drops by total of interacting (effective plus ineffective) plus those with no fire interaction, in other words the proportion of drops interacting with the main fire to all drops with known outcomes. Bands indicate the range between the worst and best cases possible, assigning all unknown outcomes as no fire interacting or fire interaction. The POS for each aircraft is the result of dividing the sample counts of effective drops by the total of effective plus ineffective drops, in other words the proportion of effective to all interacting drops. Bands indicate the range between the worst and best cases possible, assigning all unknown outcomes as either ineffective or effective.

Aircraft Effectiveness: Drop Outcomes by Ground Engagement (Airtanker only)

Figure shows the percentages of airtanker drop outcomes with (“yes” bin), without (“not at all-not mapped” bin), and unknown (“unknown-not mapped” bin) ground engagement. Relative to Figure 9, the number of drops is slightly higher due to drops with observed outcomes but no recorded drop objectives. The most common outcome for drops with ground engagement was delayed fire spread (31%) followed by no fire interaction (22%), halted fire spread (20%), and unknown (9%). The most common outcome for drops without ground engagement was not effective (26%) followed by delayed fire spread (22%), no fire interaction (15%), and unknown (15%). For the remaining 281 drops where it is unknown whether ground resources were present, the dominant outcome was unknown (48%) simply confirming the limited information available from this small subset of observations. The estimated drop POS was 0.72 with ground engagement, 0.56 without ground engagement, and 0.64 for unknown – not mapped.

Delayed fire spread was the most common outcome for drops with and without ground engagement. There was a slightly higher percentage of no fire interaction for drops with ground engagement. Drops halted fire spread about twice the percentage with ground engagement compared to without ground engagement, and a higher percentage of drops protected points successfully without ground engagement compared to with ground engagement (because it was attempted a higher percent of the time without ground engagement). The percentages of drops that burned through the line were similar with and without ground engagement, but the percentage of drops that outflanked and spotted over the line were higher without ground engagement.

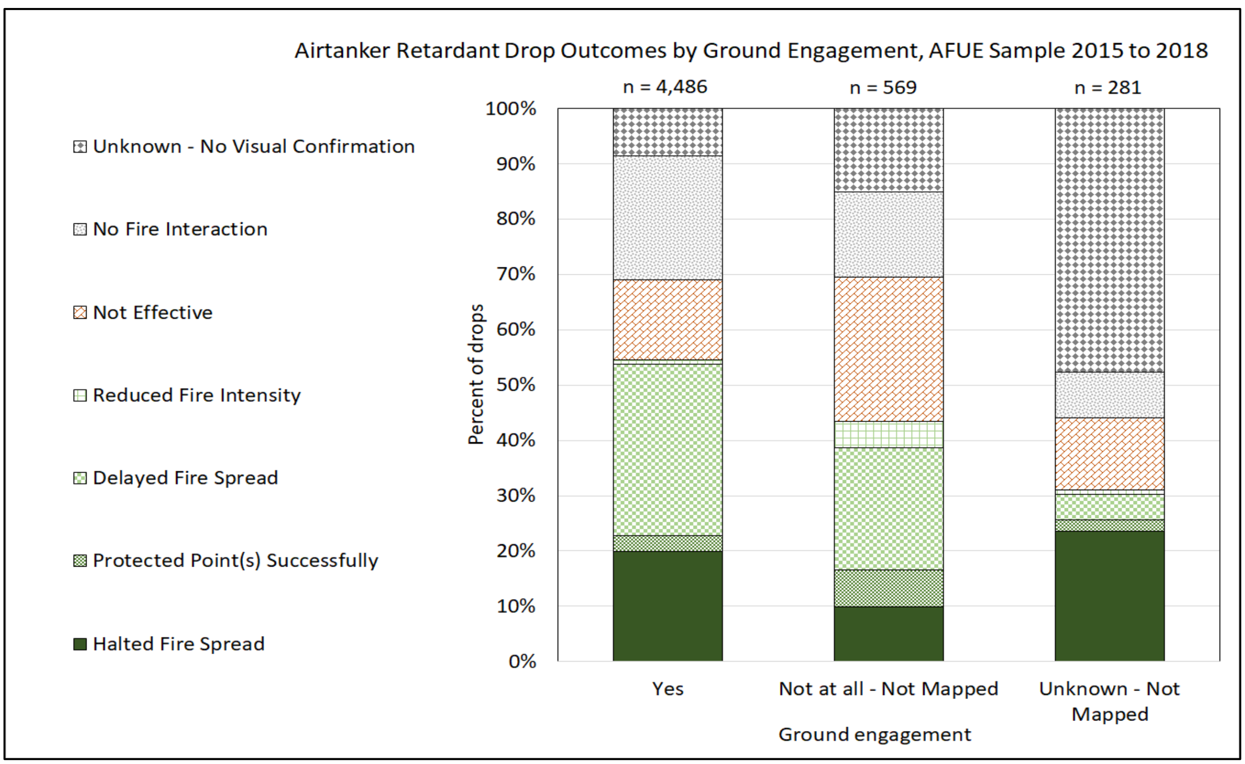


Figure 20 — Percentage of airtanker retardant drops by drop outcome with and without ground engagement. The shades of green represent positive contributions and red represents different reasons for failure (burned through the line, outflanked, spotted outside the line, failed to contribute unknown reason, change in tactics/priority, jettison).

Conclusions & Next Steps

The goal is to develop and implement performance measures, support evidence-based resource deployment decisions, and inform strategies for future aviation budgeting and contracting. To accomplish that, the AFUE study summarized the range of aircraft, fire environments, and objectives associated with aerially delivered water and retardant missions. Through this effort the relative distribution of objectives across multiple aircraft and delivery platforms and the probability of meeting site specific drop objectives was determined in the field. Direct field observation has allowed a richer understanding of mission objectives, interaction percentages, and probabilities of success for the range of platforms and conditions under which aircraft operate. These data provide a critical framework for future work to improve the effectiveness and efficiency of aviation in supporting wildfire incident objectives.

The AFUE study made a number of important contributions to the current knowledge base on aerial firefighting, as well as several important methodological contributions in terms of developing common terminology, definitions, and performance measures. Results will be shared with the fire community to inform training and development of actionable guidance for firefighters and aviation fleet managers based on empirically sound data and methods. AFUE findings could also be fed into processes of planning, assessment, monitoring, and feedback for fire managers who establish operational plans, request aircraft, and order drops to achieve tactical missions.

Future AFUE work may proceed along a number of lines, including developing additional performance metrics and exploring options to provide incident managers with dashboards and maps that show drop activity on their incidents. A particularly promising avenue is expanded collection and analysis of Additional Telemetry Unit (ATU) data, which provide a mechanism for gathering basic aviation use information and allows managers to perform real-time oversight to ensure ongoing use aligns with strategic objectives and Agency goals. Further, building a comprehensive archived ATU data repository could improve national scale accountability by providing opportunities for post-incident analysis and learning of fleet workload and usage patterns.

By investing in additional aerial data capture and analysis, the Agency could then capitalize on advances in big data analytics. For example, analysts could use machine learning algorithms to facilitate the process of designing new performance metrics through advanced statistical analysis of factors such as fuels, topography, multispectral imagery, and next-generation fire danger indices. Predictive models could also be built to help managers evaluate probability of success and determine efficient aviation strategies, and these analytics could be embedded into existing operational decision support systems.

Moving forward, there are also opportunities to embed AFUE findings and principles into broader ongoing efforts. This includes comprehensive analysis of suppression effectiveness as required by the Fiscal Year 2018 Omnibus Bill, development of next-generation decision support and resource tracking required by the “John D. Dingell, Jr. Conservation, Management, and Recreation Act,” Public Law No. 116-9, and a range of situational awareness and decision support products developed through the Risk Management Assistance program. Such efforts would enable stronger integration of firefighter tactics, with improved geospatial data on actions such as line construction, burnout operations, and point protection activities. Enhancing interoperability of information systems with interagency partners would further complement efforts to paint a more comprehensive picture of aerial firefighting use and effectiveness.

In sum, the AFUE study has effectively and comprehensively responded to recommendations from GAO-13-684 and has opened the door for additional learning and system improvement. Results will help the Agency implement performance measures, support evidence-based resource deployment decisions, and inform strategies for future aviation budgeting and contracting.

Appendix A- Aviation Asset Descriptions

LARGE AIRTANKERS

Aircraft Make/ Model	**BAe- 146-200**
Operator	Neptune
IAB Approved Tank	Full approval. Meets all coverage levels.
Retardant Gallons/ Wt.	3000/ 27,000 pounds
Speed (mph)	350

Aircraft Make/ Model	**RJ-85**
Operator	Aero Flite
IAB Approved Tank	Full Approval. Meets all coverage levels
Retardant Gallons/ Wt.	3000/ 27,000 pounds
Speed (mph)	350

Aircraft Make/ Model	**Lockheed EC-130Q**
Operator	Coulson
IAB Approved Tank	Full Approval. Meets all coverage levels
Retardant Gallons/ Wt.	4000/ 36,000 pounds
Speed (mph)	350

Aircraft Make/ Model	**Boeing MD-87**
Operator	Aero Air LLC (Erickson)
IAB Approved Tank	Full Approval. Meets all coverage levels
Retardant Gallons/ Wt.	3000/ 27,000 pounds
Speed (mph)	350

Aircraft Make/ Model	**Lockheed C-HC-130H/J**	
Operator	MAFFS - US Air Force, Air National Guard	
IAB Approved Tank	Full Approval. Meets all coverage levels	
Retardant Gallons/ Wt.	3000 (MAFFS II), 27,000 pounds	
Speed (mph)	230	

Aircraft Make/ Model	**Boeing 737-300**	
Operator	Coulson	
IAB Approved Tank	Interim during field evaluation	
Retardant Gallons/ Wt.	4000/ 36,000 pounds	
Speed (mph)	350	

Aircraft Make/ Model	**Viking Q-400**	
Operator	Aero Flite and France	
IAB Approved Tank	Interim approval through 2020	
Retardant Gallons/ Wt.	2600/ 23,400 pounds	
Speed (mph)	375	

VERY LARGE AIRTANKERS

Aircraft Make/ Model	**DC-10**	
Operator	10 Tanker	
IAB Approved Tank	Full approval. Meets all coverage levels.	
Retardant Gallons/ Wt.	9,400/ 84,600 pounds	
Speed (mph)	350	

Aircraft Make/ Model	**Boeing 747-400**	
Operator	Global Supertanker	
IAB Approved Tank	Interim through 2020.	
Retardant Gallons/ Wt.	18,000/ 162,000 pounds	
Speed (mph)	450	

SINGLE ENGINE AIRTANKER

Aircraft Make/ Model	**Air Tractor 802**	
Operator	Various	
IAB Approved Tank	NA	
Retardant Gallons/ Wt.	800/ 7200 pounds	
Speed (mph)	200	

WATER SCOOPERS

Aircraft Make/ Model	**Viking CL-415**	
Operator	Aero Flite and several Canadian Provinces	
IAB Approved Tank	Yes	
Water Gallons/ Wt.	1620/ 12,960 pounds	
Speed (mph)	200	

Aircraft Make/ Model	**Air Tractor Fire Boss**	
Operator	Various	
IAB Approved Tank	NA	
Water Gallons/ Wt.	700/5600 pounds	
Speed (mph)	170	

HEAVY – TYPE 1 HELICOPTERS

Helicopter Make/ Model	**Sikorsky/ Erickson S-64E/F**
Operator	Erickson, Heli Transport Svcs. & Siller
Bucket/ Tank Gallons	~2500
Speed (mph)	132

Helicopter Make/ Model	**Sikorsky CH-54 A/B**
Operator	Helicopter Transport Svcs. & Siller
Bucket/ Tank Gallons	~2500
Speed (mph)	132

Helicopter Make/ Model	**Boeing BV-234**
Operator	Columbia
Bucket/ Tank Gallons	~3000
Speed (mph)	175

Helicopter Make/ Model	**Boeing CH-47 "Chinook"**
Operator	Billings Flying Svc., Columbia, Helimax
Bucket/ Tank Gallons	~3000
Speed (mph)	175

Helicopter Make/ Model	**Boeing BV-107-II**	
Operator	Columbia	
Bucket/ Tank Gallons	~1100	
Speed (mph)	138	

Helicopter Make/ Model	**Boeing CH-46E “Sea Knight”**	
Operator	Sky Aviation	
Bucket/ Tank Gallons	~1100	
Speed (mph)	138	

Helicopter Make/ Model	**Sikorsky S-61 A/N/ SH-3H**	
Operator	Coulson, Croman, HTS and Siller	
Bucket/Tank Gallons	~500	
Speed (mph)	138	

Helicopter Make/ Model	**Sikorsky S-70/ UH-60 NG**	
Operator	Firehawk Helicopters, PJ Helicopters, LA County & BLM	
Bucket/ Tank Gallons	~900	
Speed (mph)	180	

Helicopter Make/ Model	**Kaman K-1200**	
Operator	Various	
Bucket	~680	
Speed (mph)	90	

Helicopter Make/ Model	**Airbus H215/225 NG**
Operator	Various
Bucket	~1000
Speed (mph)	160

MEDIUM – TYPE 2

Helicopter Make/ Model	**Bell 205 / 210 and UH-1**
Operator	Various
Bucket/Tank	~500
Speed (mph)	121

Helicopter Make/ Model	**Bell 212 HP**
Operator	Various
Bucket/Tank	~350
Speed (mph)	132

Helicopter Make/ Model	**Bell AH-1**
Operator	USFS
Bucket/Tank	None.
Speed (mph)	219

Helicopter Make/ Model	**Bell 412**
Operator	City and County Fire Departments. Commercial operators
Bucket/Tank	~360
Speed (mph)	140

LIGHT – TYPE 3 HELICOPTERS

Helicopter Make/ Model	**Airbus H125** **NG**
Operator	Various
Cruise Speed kts/mph	157
Passengers/ Gallons	5/ ~ 260

Helicopter Make/ Model	**Bell 407** **NG**
Operator	Various
Cruise Speed kts/mph	136/152
Passengers/ Gallons	6/ ~ 270

Helicopter Make/ Model	**Bell 206 L3/4**
Cruise Speed kts/mph	110/127
Passengers/ Gallons	6/ ~ 225

Helicopter Make/ Model	**Bell 206 B3**	
Operator	Various	
Cruise Speed kts/mph	110/127	
Passengers/ Gallons	4/ ~ 160	

Helicopter Make/ Model	**MD- 500 C/D/E and 530F**	
Operator	Various	
Cruise Speed kts/mph	135/155	
Passengers/ Gallons	5/ ~ 160	

Helicopter Make/ Model	**MD- 520N/ 600N**	
Operator	Various	
Cruise Speed kts/mph	134/154 (Explorer)	
Passengers/ Gallons	6/ ~ 300 (Explorer)	

Helicopter Make/ Model	**Sikorsky S-76++/ D**	
Operator	Coulson	
Cruise Speed kts/mph	155/178	
Passengers/ Gallons	12/ ~ 300	

NOT TYPED HELICOPTER

Helicopter Make/ Model	**Agusta-Westland AW-119 NG**	
Operator	Various	
Cruise Speed kts/mph	140/150	
Passengers/ Gallons	8/ ~ 315	

Helicopter Make/ Model	**Agusta-Westland AW-109 NG**	
Operator	Various	
Cruise Speed kts/mph	154/177	
Passengers/ Gallons	7/ ~ 200	

Helicopter Make/ Model	**Agusta-Westland AW-139 NG**	
Operator	Various	
Passengers/ Gallons	12/ ~ 420	

Helicopter Make/ Model	**Bell 429 NG**	
Operator	Various	
Cruise Speed kts/mph	154/177	
Passengers/ Gallons	7/ ~250	

Helicopter Make/ Model	**Airbus H130 NG**	
Operator	Various	
Cruise Speed kts/mph	123/141 (120)	
Passengers/ Gallons	4/ ~ 180 (120)	

Helicopter Make/ Model	**Airbus H135/ 145 NG**
Operator	Various
Cruise Speed kts/mph	123/141 (145)
Passengers/ Gallons	4/ ~ 180 (145)

LARGE AIRCRAFT

Aircraft Make/ Model	**Boeing 737-500**
Operator	Sierra Pacific
Mission(s)	Passenger Transport
Passengers/ Speed (mph)	101/ 480

Aircraft Make/ Model	**Short Bros. SD3-60 Sherpa**
Operator	USFS
Mission(s)	Smokejumper, Cargo and Passenger Transport
Passengers/ Speed (mph)	10 Smokejumpers, <15 passengers/ 240

Aircraft Make/ Model	**CASA 212**
Operator	Bighorn Airways
Mission(s)	Smokejumpers and para-cargo
Passengers/ Speed (mph)	8 smokejumpers/180

Aircraft Make/ Model	**Dornier 228**
Operator	Bighorn Airways
Mission(s)	Smokejumpers and para-cargo
Passengers/ Speed (mph)	8 smokejumpers/ 215

Aircraft Make/ Model	Viking DHC-8	
Operator	Bighorn Airways	
Mission(s)	Smokejumpers and para-cargo	
Passengers/ Speed (mph)	10 smokejumpers/ 310	

LIGHT AIRCRAFT

Aircraft Make/ Model	**Viking DHC-6 Twin Otter**	
Operator	USFS and Leading Edge	
Missions(s)	Smokejumper, para-cargo and passenger	
Passengers/ Speed (mph)	8 smokejumpers / 190	

Aircraft Make/ Model	**Cessna Citation II 550**	
Operator	USFS	
Mission	Fire mapping, Infrared and passenger transport	
Passengers/ Speed (mph)	8/ 450	

Aircraft Make/ Model	**Beech King Air 200/250**	
Operator	USFS and various	
Mission	Fire mapping, Infrared, air attack and diverse missions	
Passengers/ Speed (mph)	7/ 300	

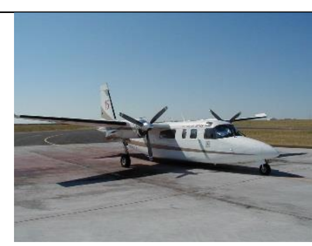
Aircraft Make/ Model	**DeHavilland DHC-2 Beaver**	
Operator	USFS	
Mission	Water dropping and diverse missions	
Passengers/ Speed (mph)	6/ 140	

Aircraft Make/ Model	**Cessna 206 Station Air**	
Operator	USFS and various	
Mission	Recon, air attack and diverse missions	
Passengers/ Speed (mph)	5/160	

Aircraft Make/ Model	**Quest Kodiak 100**	
Operator	USFS and USFW	
Mission	Recon, air attack and diverse missions	
Passengers/ Speed (mph)	9/200	

Aircraft Make/ Model	**Aero Commander 500**	
Operator	Various	
Mission	Air attack, fire mapping, Infrared and diverse missions	
Passengers/ Speed (mph)	4/ 200	

Aircraft Make/ Model	**Piper Baron P-58**	
Operator	Various	
Mission	Air attack	
Passengers/ Speed (mph)	5/ 200	

Aircraft Make/ Model	**Twin Commander 680/690**	
Operator	Various	
Mission	Air attack	
Passengers/ Speed (mph)	7/ 320	

Aircraft Make/ Model	**Cessna 182**
Operator	Various
Mission(s)	Diverse missions including recon, backcountry and resource management
Passengers/ Speed (mph)	3/167

Aircraft Make/ Model	**Beech King Air 90 GT**
Operator	Tenax and various
Mission	Aerial Supervision/Leadplane, air attack and diverse missions
Passengers/ Speed (mph)	5/260

Aircraft Make/ Model	**Beech King Air 200GT**
Operator	Tenax
Mission	Aerial Supervision/Leadplane, air attack and diverse missions
Passengers/ Speed (mph)	7/ 330