Analysis of Aerial Firefighting with Rotorcraft Platforms

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ABSTRACT

Wildfires are an annual torment in many parts of the world. They can spread very quickly and destroy forests, wildlife, buildings, infrastructure, and homes, as well as risk human life before they are able to be controlled. Because of the rapid response time that is necessary to extinguish a wildfire before it becomes too large, the quantity and speed of water delivery are extremely important – helicopters are a great tool for accomplishing this goal. They can fly directly to the fire and refill their water supply from smaller, more remote water sources than other aerial platform options require. There are several water tank options to transport and drop water on the fire from a helicopter. This paper focuses on four of these options: an external rigid tank, an accordion tank, a Bambi Bucket®[1], and an internal tank in addition to the outlining some of the options for remote water sourcing. Each of these tank types have various advantages and disadvantages which are discussed using models developed for evaluating helicopter firefighting applications.

INTRODUCTION

Wildfires have raged across the globe since the beginning of time. Man has steadily developed methods and tools to fight and control wildfires throughout the past 50 years. According to the Department of Natural Resources, over the period from 1992 through 2015, the Acres Burned by Wildfires in Oregon and Washington has trended up from around 100,000 in 1992 to about 1,000,000 acres in 2015. Consequently, wildfire costs have increased from $0.92 billion from 1992-1999 to $3.13 billion from 2000-2012 at the federal level with the trend increasing year over year. As stated in the Washington Wildland Fire Protection Strategic Plan, "The trends in wildfires suggest we need to improve how we manage wildfires."[2] The trend going forward is likely to escalate with a projected increase in fire frequency, severity, and consequent damages in terms of loss of life and economic losses such as utilities, restoration costs, individual property losses, and insurance costs. Helicopters have become an integral tool to help fight the growth of wildfires.

The earliest documented use of helicopters to fight fires dates back to the late 1940s. At that time, helicopters were used primarily for observing and mapping fires for ground-based crews to effectively fight them safely. This practice continued throughout the 1950s and part way through the 1960s. When the Winter Ridge Fire in Southern Oregon broke out in 1966, the role of the helicopter in firefighting drastically changed. Engineers at Columbia Helicopters suspended a crude construction bucket from a helicopter to haul water from a creek onto the fire.[3] The concept of fighting fires from the air was changed forever.

In addition to fixed wing, ground-based vehicles, and firefighters, helicopters have become one of the most effective assets in the fight against wildfires. Since the first bucket design—later becoming what is known as the Bambi Bucket® in the 1980s—helicopters have taken a significant role in how wildfires are fought across the globe. In the years since, many more technologies have come into service.

Each platform and delivery method offers unique benefits which enhance their overall value. This paper investigates effects on the amount of water able to be delivered, how quickly that water can be delivered, the multi-role capability to support operations outside of water delivery. These include smoke-jumper insertion, food, water, and equipment resupply to ground crews, search and rescue operations, and all-weather day/night capability to keep the fire under control in challenging conditions.

Helicopters today can operate much closer to the fire, fill their tanks from local water supplies, reduce the time between drops and stay on station longer to support the ground crews. New technologies in rotorcraft, avionics, computing, and water tank fill technologies continue to help optimize the application of each platform to fight fires most effectively.

A typical firefighting mission, shown in Figure 1, is composed of several segments: initial attack (total distance from the airbase to the water), mission distance (distance from the water to the fire), water drop, water fill/snorkel, and refuel. The time needed to get water to fire drives mission effectiveness in this model.

Presented at the Vertical Flight Society's 79th Annual Forum & Technology Display, West Palm Beach, FL, USA, May 16-18, 2023.

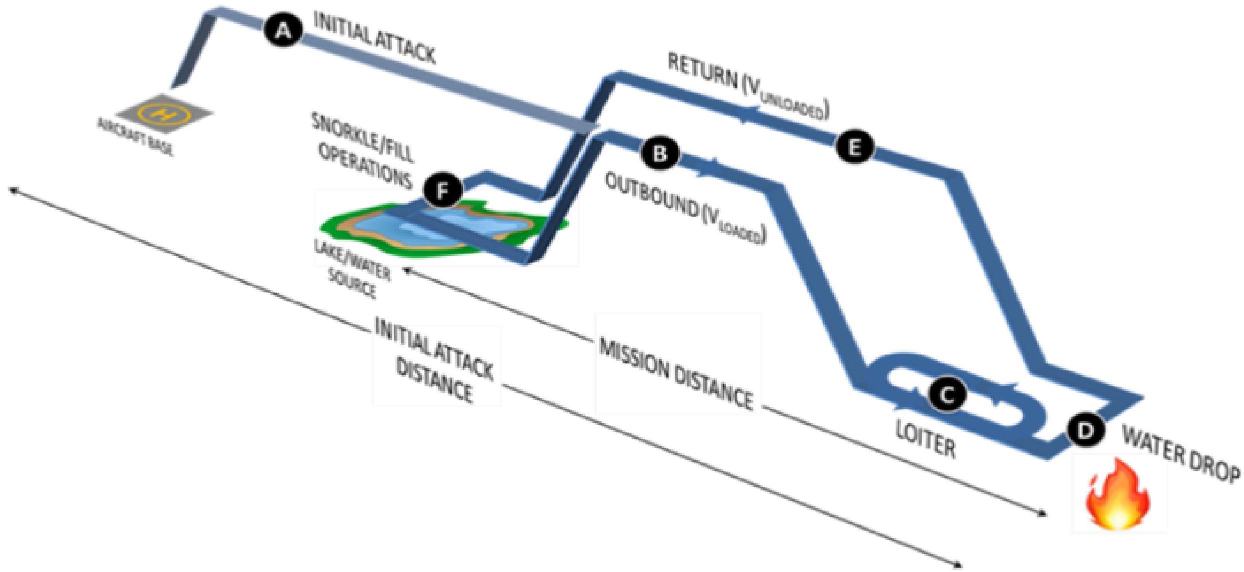

Figure 1. Typical helicopter firefighting mission profile.

This paper reviews a range of rotary-wing firefighting equipment and technologies—including how each of them may fit into a firefighting organization—providing insight as to how the various equipment can most efficiently provide fire retardant to support ground crews in fighting wildfires. During a fire, the most important activity is delivering water, and the faster that is done, the higher the probability is that the fire will be extinguished without severe damage.

ROTORCRAFT FIREFIGHTING TECHNOLOGIES

Over the past 50 years, many different technologies have been developed for helicopters to get water onto fires as quickly and efficiently as possible. These technologies range from water carriage methods to fill pumps and ground-based mobile fill stations that can be positioned close to a fire. Each of these has its own benefits and detriments which are discussed below.

Bambi Bucket®

The Bambi Bucket® (shown in Figure 2) is one of the most versatile and widespread water carriage options. SEI Industries Ltd. introduced the original Bambi Bucket® back in 1982. Per SEI Industries Ltd., over 115 countries and more than 1000 operators use Bambi Bucket® to fight fires.[4] Bambi Bucket® come in a range of sizes from 72-gal up to 2,590-gal, and they offer power fill pumps and snorkel to enable shallow water bucket fill capability in as little as 18 inches of water. The basic configuration requires the operator to dip the bucket into the water to fill the tank. All water release and control of the Bambi Bucket® operation is managed via an independent control head which can operate for 10 hours of firefighting operations before needing a recharge. The Bambi Bucket® is widespread because of its ease of integration onto nearly any helicopter platform without need for configuration change. It is lightweight, it can operate in a wide variety of locations and conditions, and it can be removed quickly when necessary.

Figure 2. Bambi Bucket® delivering water.[5]

One of the challenges of operating a Bambi Bucket® is the flight speed limitation it imposes during operations. In addition, the bucket hangs 50-100 ft. below the aircraft resulting in a risk to entanglement with trees or powerlines. Because it operates using a cargo hook, the aircraft speed is normally limited to approximately 80 kts due to flight loads and load instability. The Federal Aviation Regulations (FAR) also restricts the use of the bucket above populated areas potentially resulting in lower operational effectiveness. Additionally, the rotor downwash could negatively impact precision water fill operations.

Internal Tank

Internal water tanks, which are shown in Figure 3, have been employed in several platforms such as the UH-60, UH-1, CH-47 Chinook, H215 and the S-64 SKYCRANE™. Internal tanks offer the ability to remain aerodynamically efficient throughout the water carriage cycle, avoiding the complications that external loads present such as reduced flight envelope and load instability.

However, the use of an internal tank results in the cabin being unavailable for any other purpose, such as transporting firefighters or equipment to fire location, while the tank is installed. The use of snorkel allows for the quick filling of the tanks from remote and shallow water sources, allowing a short turnaround time to and from the fire. Internal tanks can also be filled directly from a water hose such as from a fire truck. Internal water tanks are great options for a dedicated firefighting platform, but they prevent multipurpose operations while installed. They are also much more cumbersome to install and remove. They require a higher level of integration with the host platform and are typically more expensive to purchase.

Figure 3. Internal water tank with snorkel.[6]

External Hard-Sided Tank

Two types of tanks can be mounted externally to the aircraft: hard-sided external tanks and collapsible/accordion style tanks. External hard-sided tanks, shown in Figure 4, offer a combination of the benefits of the Bambi Bucket® and the internal tank technologies. On the S-70M FIREHAWK® and the B412EPI, a hard-sided tank is attached externally to the fuselage and provides a full cabin for multi-purpose use. The snorkel is very similar to those in the internal tank and fill the external tank very quickly (e.g., 45 seconds for a 1,000-gal tank). The aircraft does not require any reconfiguration to change from a water carrier to a firefighter carrier if needed. The aircraft can fill from a wide variety of water sources. Hard-sided tanks, however, require more integration effort and weigh more than an internal tank or Bambi Bucket® solution. Conversely, there is no significant impact on the flight envelope of the aircraft, allowing for a shorter fire-water cycle. Because of its effectiveness, versatility and multi-mission capability, this platform configuration has become widely utilized by organizations like L.A. County Fire and CAL FIRE.

Figure 4. External hard-sided tank on a FIREHAWK®.[7]

Accordion Tank

The second type of external water tank in service today is the collapsible, or accordion, style tank developed by Helitak. An example of the accordion tank is shown in Figure 5 (in air) and Figure 6 (collapsed). This is a relatively new technology which offers higher capacity in a similar form factor to the external hard tank.

Figure 5. External accordion water tank – filled.[8]

Figure 6. External accordion water tank – empty.[9]

The accordion tank has the same water fill capability as a hard or internal tank while hovering, but it cannot be filled while on the ground. It has a low profile while on the ground but expands when filled with water. Due to its lighter weight than a hard-sided external tank, additional water payload can be delivered to the fire. The installation of this type of tank does not require as many changes to the carrier airframe as the hard tank, but installation and removal would be a similar effort. This tank configuration presents a similar drag profile as the hard-sided external tank when empty, but when filled, the airspeed is reduced due to aerodynamic drag and flight loads. accordion tanks come in a spectrum of sizes to fit light helicopters with a 340-gal capacity up to tanks with 2,640-gal capacity, and the tank requires a specific pump which Helitak offers.[10]

Remote Water Sources

In cases where natural water sources are too far from the fire or are in locations where helicopters cannot access the water, solutions have been developed to provide temporary water sources for helicopters to access near to a fire. These solutions reduce the travel time from water to fire and increase the rate at which water can be delivered where it is needed most. With the current technologies any of these helicopter-mounted tanks can be filled with water from sources as shallow as 18 inches. It is difficult for crews to find water sources that are deep enough to be accessible by helicopter in complex terrain. In locations like the Rocky Mountains or the West coast of the United States, water may not be accessible at all from the surface during a large portion of the year, particularly in fire season, due to heat and drought. In times of drought, many water sources that are typically available such as creeks, streams and shallow ponds dry up, making it difficult to find water sources close to a fire. Figure 7 illustrates one of these remote water sources where a FIREHAWK fills its external tank via snorkel.

Figure 7. L.A. County FIREHAWK® filling from a remote fill tank at 69 Bravo Helistop.[11,12]

Several solutions have been developed to solve this problem. One is the Fireflex Pumpkin Tank developed by SEI Industries shown in Figure 7. L.A. County FIREHAWK® filling from a remote fill tank at 69 Bravo Helistop.. The pumpkin tank can be moved into position quickly; it collapses for storage and comes in a range of sizes to fit different hoses or buckets. The Pumpkins are filled via an external pump and can be positioned in remote or isolated areas. This is a relatively inexpensive solution but may require maintenance, monitoring, and managing water sources during operations.

One of the more recent developments in water storage is the HeloPod®[13] seen in Figure 8. This is a tank which can fill itself with water automatically and while unattended. It can be quickly moved into position via truck or heavy lift helicopter and provide thousands of gallons of water at or near the fire to both snorkel-fill helicopters and Bambi Bucket® to substantially increase the water dropped per hour and eliminate the need for the helicopter to land to take in water. These tanks can be connected to a fixed water source such as a fire hydrant or an external pump to fill and include features to maintain water level, provide water level, and allow the mixing of gels into the water to enhance the fire-retardant capability. The HeloPod® can be re-positioned as required and used to support operations at a different location very quickly.[14]

Figure 8. CAL FIRE FireHawk hovering over a HeloPod®.[15]

Another type of remote water source is the Heli-Hydrant (Figure 9) which is used for fixed base locations. It has an automatic re-fill float and pilot control drain/fill valves. This is a permanent base-type technology and allows for dipping and snorkeling of water. While not as flexible as some of the other types of tanks, it provides a steady source of water for firefighting operations, particularly when water is hard to find.[16]

Figure 9. Orange County Fire Authority Helicopter hovering over Heli-Hydrant.[17]

An additional option to transport water to the helicopter is to use a water tanker truck. With a large capacity (~6,000-gal) the tanker can provide enough water for 6-8 fills before the truck needs to return to its water source to refill.

Figure 10. Filling from a Water Tanker.[18]

Modeling Approach

Every helicopter has its own performance characteristics, operational capabilities, and firefighting utility, but to make the analysis as comparable as possible between the tank types, a single base helicopter was utilized. The baseline helicopter was based on the UH-60 Black Hawk®, representing a medium-sized helicopter for this analysis.

As discussed above, there are many different methods to deliver water to a fire location. Each tank configuration was applied to the baseline helicopter and the appropriate flight limitations were applied for airspeed and max gross weight limitations to evaluate the different types of water tanks with no direct aircraft comparison. Each of the four aircraft tank configurations: external hard-sided tank, external accordion tank, Bambi Bucket®, and internal tank, were then evaluated in an eight-hour firefighting mission. The analysis modeled performance at sea-level, ISA+20°C ambient conditions with varying attack distances (aircraft base station to the water source) and mission distances (water source to the fire) following the mission profile in Figure 1. Table 1 shows aircraft characteristics used in the firefighting mission model.

Table 1. Aircraft configuration characteristics.

	Firefighting Configuration			
Aircraft Attribute	**External Tank**	**Accordion Tank**	**Bambi Bucket**	**Internal Tank**
Operating Weight Empty (lbs / kg)	13,000 / 5,897			
Max TOGW (lbs / kg)	23,000 / 10,433			
Water Tank System Weight (lbs / kg)	1,600 / 726	720 / 327	270 / 122	1,380 / 626
Useful Load (lbs / kg)	8,400 / 3,810	9,280 / 4,209	9,730 / 4,413	8,620 / 3,910
Water Tank Capacity (gal / L)	1,000 / 3,785	1,200 / 4,542	680 / 2,574	1,000 / 3,785
Speed Unloaded (kts / kph)	140 / 259	120 / 222	80 / 148	140 / 259
Speed Loaded (kts / kph)	130 / 241	100 / 185	80 / 148	130 / 241
Fuel Tank Capacity (gal / L)	350 / 1,325			
Cabin Seating	12	12	12	0
Direct Operating Cost ($/FH)	3,000			

The four model outcome measures are Total Water Dropped (gal), Total Number of Water Drops (#), Direct Operating Cost per Gallon Dropped ($/gal), and Time Needed per Water Cycle (min). A water cycle is the time needed to fill the water tank, fly to the fire location, drop water, and return to the water source to refill the tank. A series of scenarios were modeled based on all possible combinations of inputs. Results from the maximum water delivery scenario, which is based on the shortest attack and mission distances over an 8-hr mission length, are illustrated in Figure 11 and Figure 12. Figure 12 shows water delivery buildup over time for the maximum water delivery scenario. The final values at the end of the 8-hr mission correspond to the Total Water Dropped values in the model.

The external hard-sided, accordion, and internal tanks all deliver approximately the same amount of water during the mission, but the Bambi Bucket® only is able to deliver 60% of the other configurations. This is primarily due to the airspeed limitations when using a Bambi Bucket®. Both the external hard-sided and internal tank configurations are capable of performing the same number of water drops due to their similar airspeeds and lack of any restrictions. In contrast, the airspeed limitations of the accordion and Bambi Bucket® configurations reduce the number of water delivery cycles that can be executed in the 8-hour mission. Consequently, in missions with short attack and mission distances, the external hard-sided tank, accordion tank, and internal tank configurations result in approximately the same cost per gallon of water dropped while the Bambi Bucket® is much more expensive to operate.

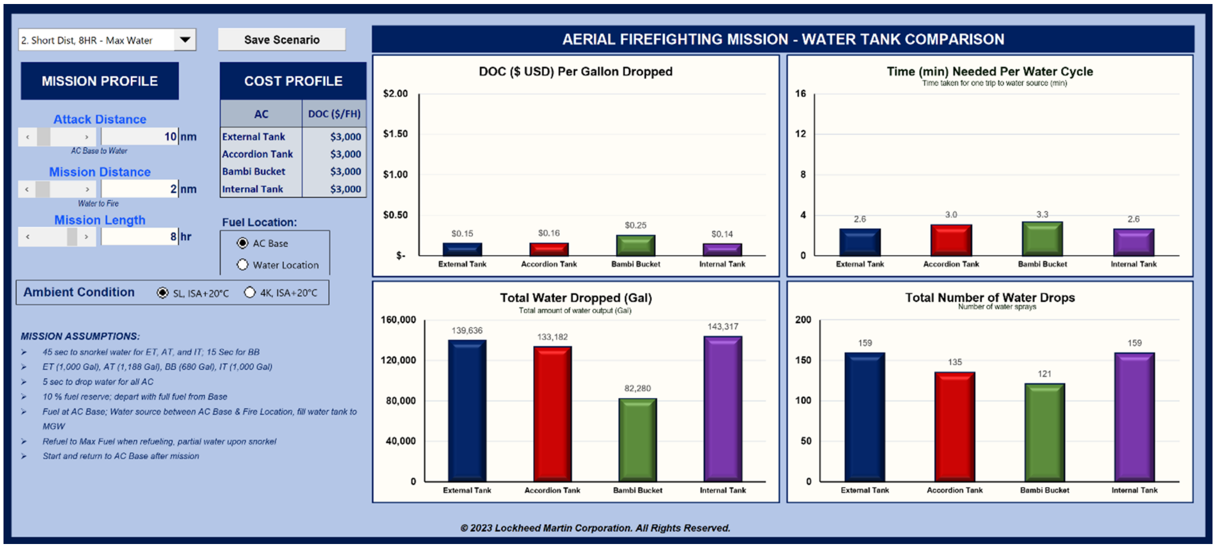

Figure 11. Results for maximum water delivery scenario.

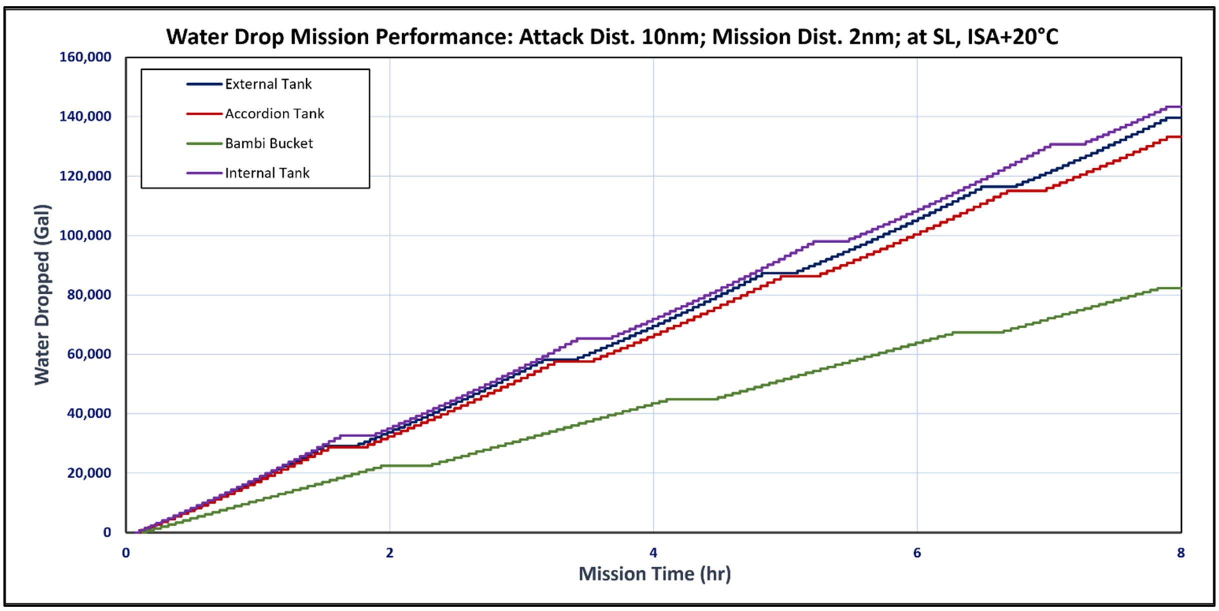

Figure 12. Water delivery chart for maximum water delivery scenario.

Figure 13 and Figure 14 show a scenario depicting longest attack and mission distances that result in a mission scenario that's most expensive to execute (Maximum Direct Operating Cost). As attack and mission distance increase, the differences between each helicopter configuration for the water volume dropped and cost per gallon measures increase. The internal tank configuration out-performs the external hard-sided and accordion configurations in both cost (less expensive to operate) and the amount of water delivered (gallons dropped). The helicopter equipped with an external hard-sided tank outperforms the accordion tank configuration as well in all four measures. The Bambi Bucket® remains the most expensive to operate with the least amount of water delivered.

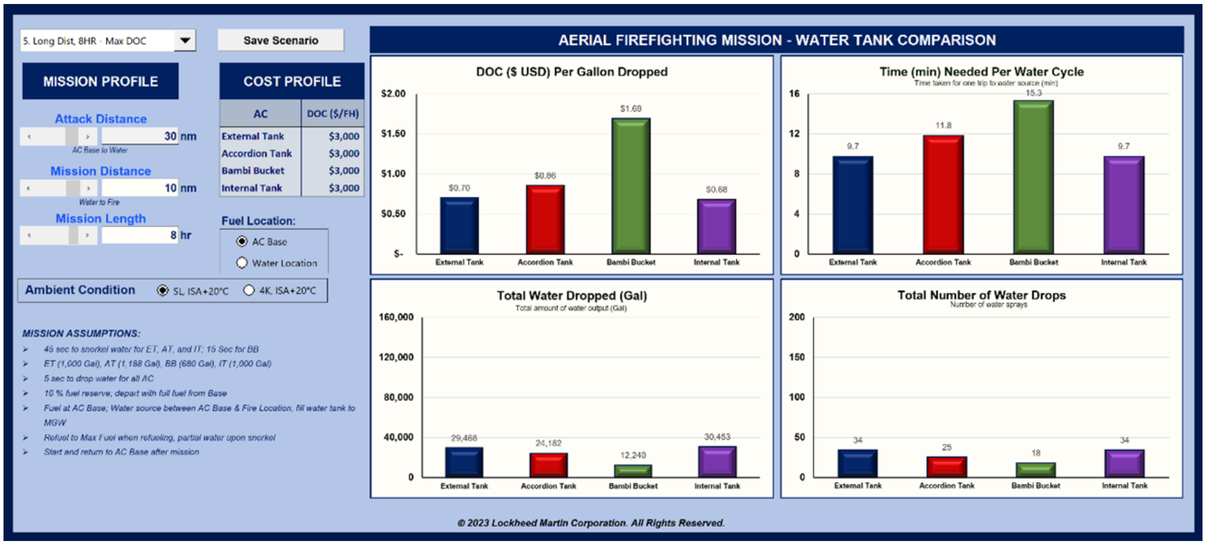

Figure 13. Results for maximum direct operating cost (DOC) scenario.

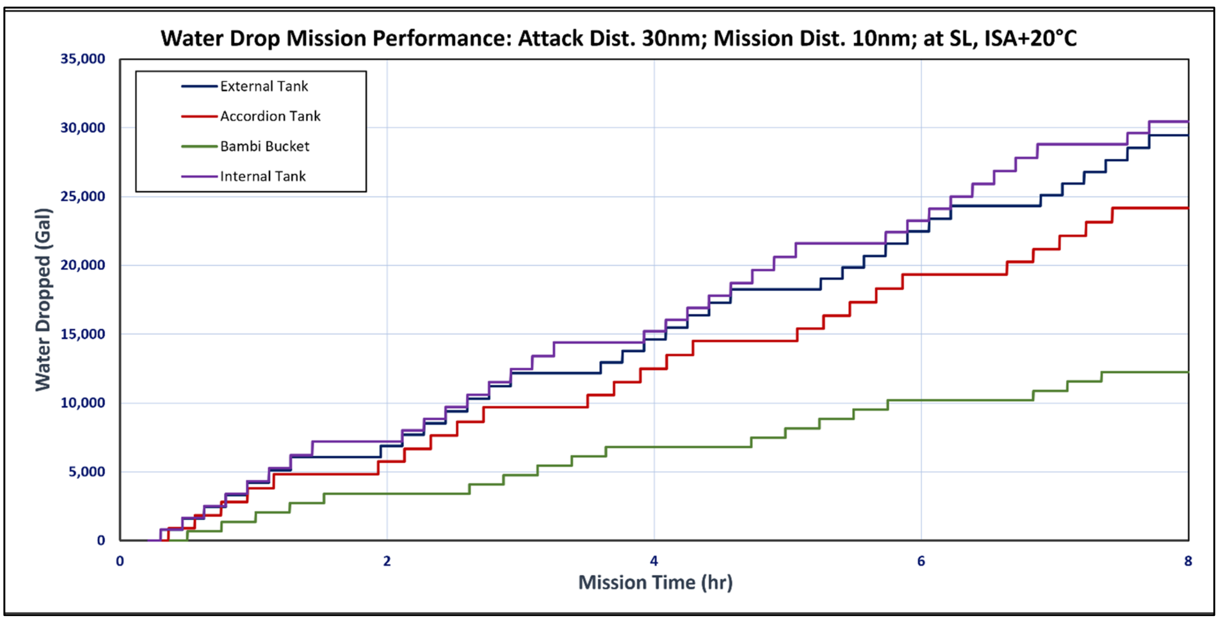

Figure 14. Water delivery chart for maximum direct operating cost (DOC) scenario.

In both scenarios, the helicopter configurations equipped with the external hard-sided tank and the internal tank have the greatest airspeed and therefore complete the water cycle in the least amount of time and execute the most water drops.

By using the firefighting mission model above to iterate over a large set of distances, it was possible to create a radius performance model showing the firefighting effectiveness at varying mission radii. This model compiles the entire data set from the water delivery performance model in order to create heat maps around air stations on a map. The model calculates interactions between helicopters dispatched from different stations and the total amount of water that can be delivered at any point on the map for a given workday length. Examples of this model are shown in Figure 15, Figure 16, Figure 17, and Figure 18.

The four figures represent the four different types of water tanks on a medium lift helicopter with all other variables being set equal. Four air stations were selected in order to cover all or most of the state of Connecticut (5,015 square miles), Rhode Island (1,214 square miles), Long Island (1,401 square miles) as well as a small portion of eastern NY and southern Massachusetts. The four stations are Bradley International, Hudson Valley Regional, Groton-New London, and Sikorsky Memorial. Figure 15 shows the water delivery performance of the external hard-sided tank helicopter configuration. The solid rings represent the 20-minute response radius of the aircraft. The response time value can be adjusted, and the rings are a reference that enable the user to determine response time to a fire at a given distance away from one or more stations. The blue heat map represents the density of water delivered at a particular location on the map.

The darker the blue tint is, the more water that can be dropped on a fire at that location.

From the maps, it is evident that the external hard-sided tank, accordion tank, and internal tank configurations each perform comparable to each other in terms of range and water delivery.

The Bambi Bucket® configuration is not capable of delivering as much water as the other configurations, and due to water capacity and airspeed limitations for a medium-lift helicopter, the 20-minute response range is greatly reduced.

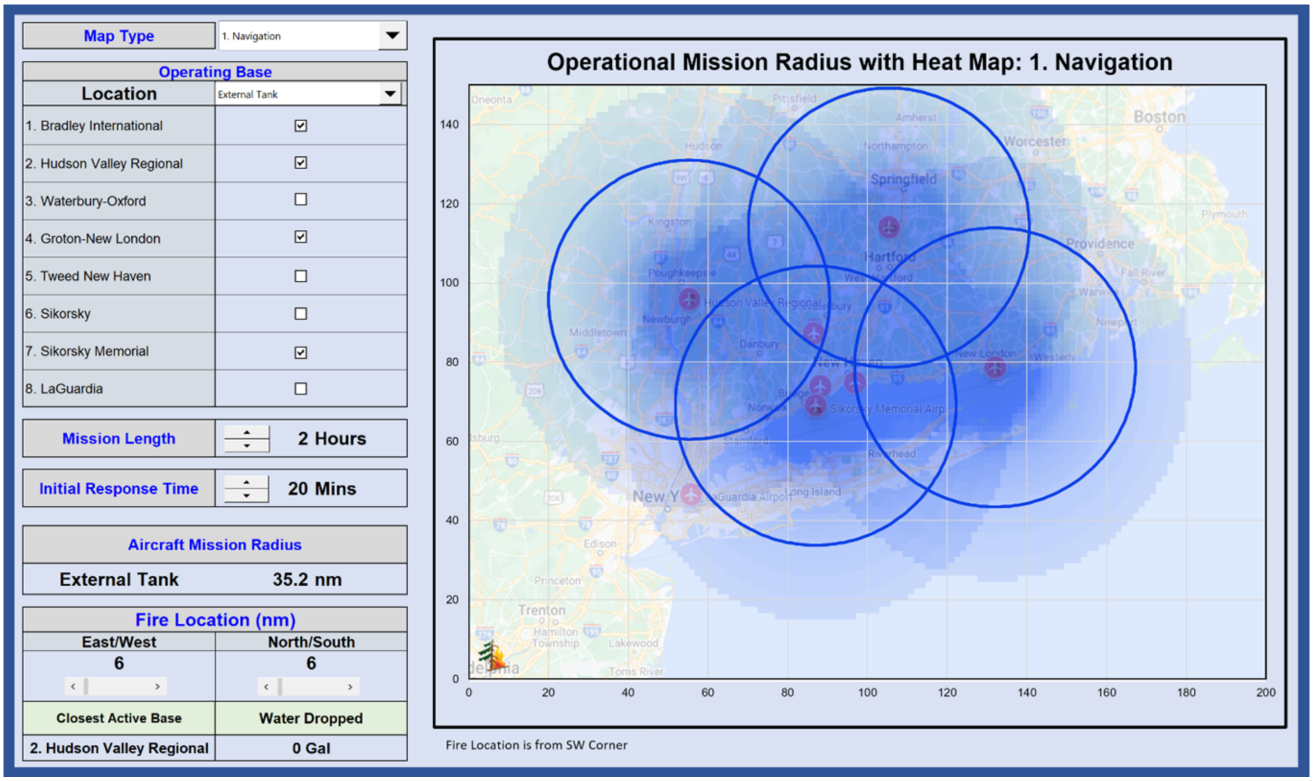

Figure 15. Mission radius model showing water delivery capability of four medium-lift helicopters using an external hard-sided tank; stationed at Bradley International, Hudson Valley, Groton-New London, & Sikorsky Memorial.

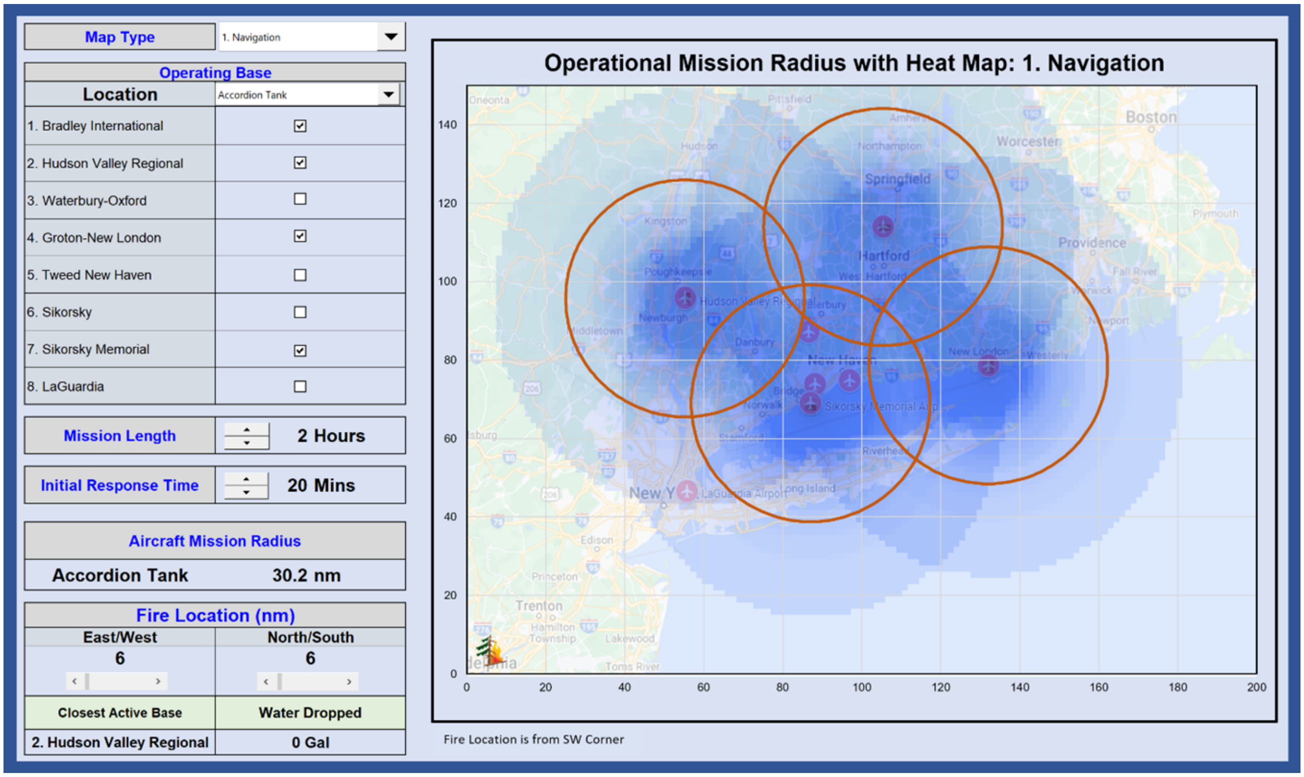

Figure 16. Mission radius model showing water delivery capability of four medium-lift helicopters using an accordion tank; stationed at Bradley International, Hudson Valley, Groton-New London, & Sikorsky Memorial.

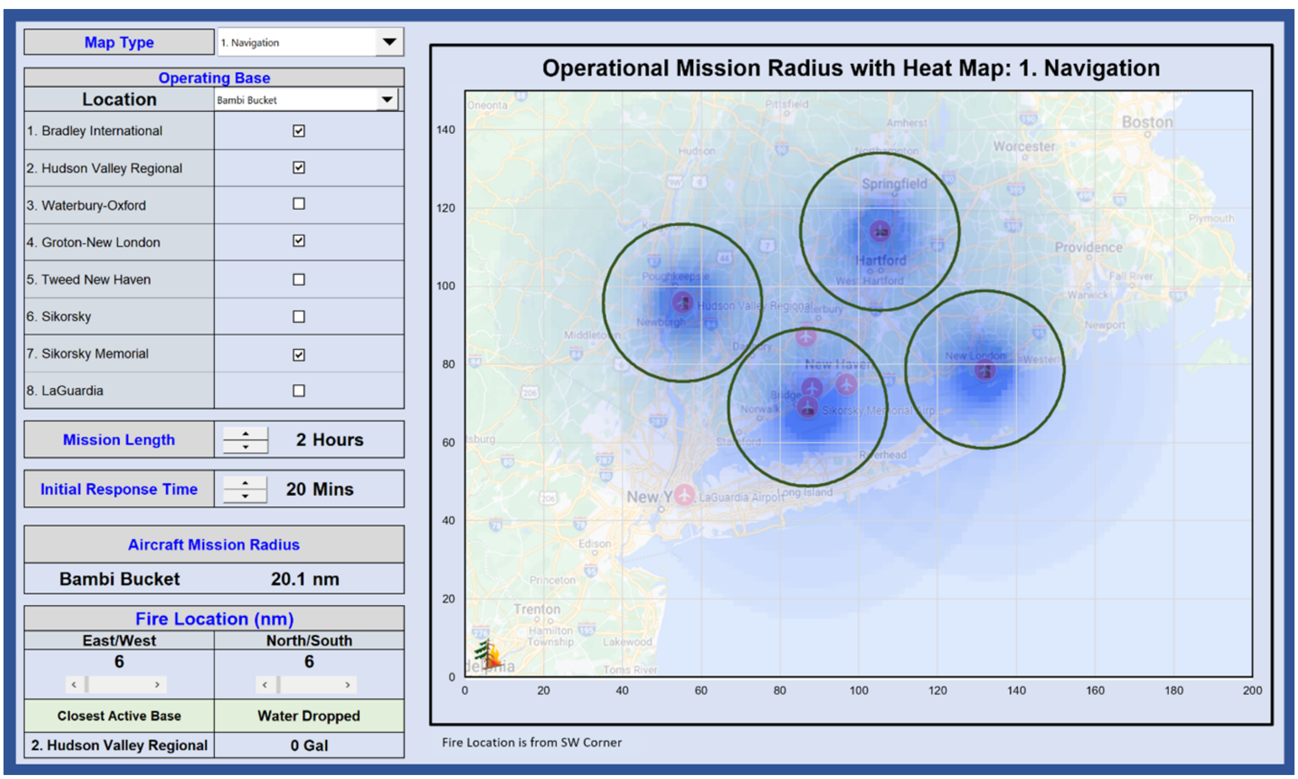

Figure 17. Mission radius model showing water delivery capability of four medium-lift helicopters using a Bambi Bucket®; stationed at Bradley International, Hudson Valley, Groton-New London, & Sikorsky Memorial.

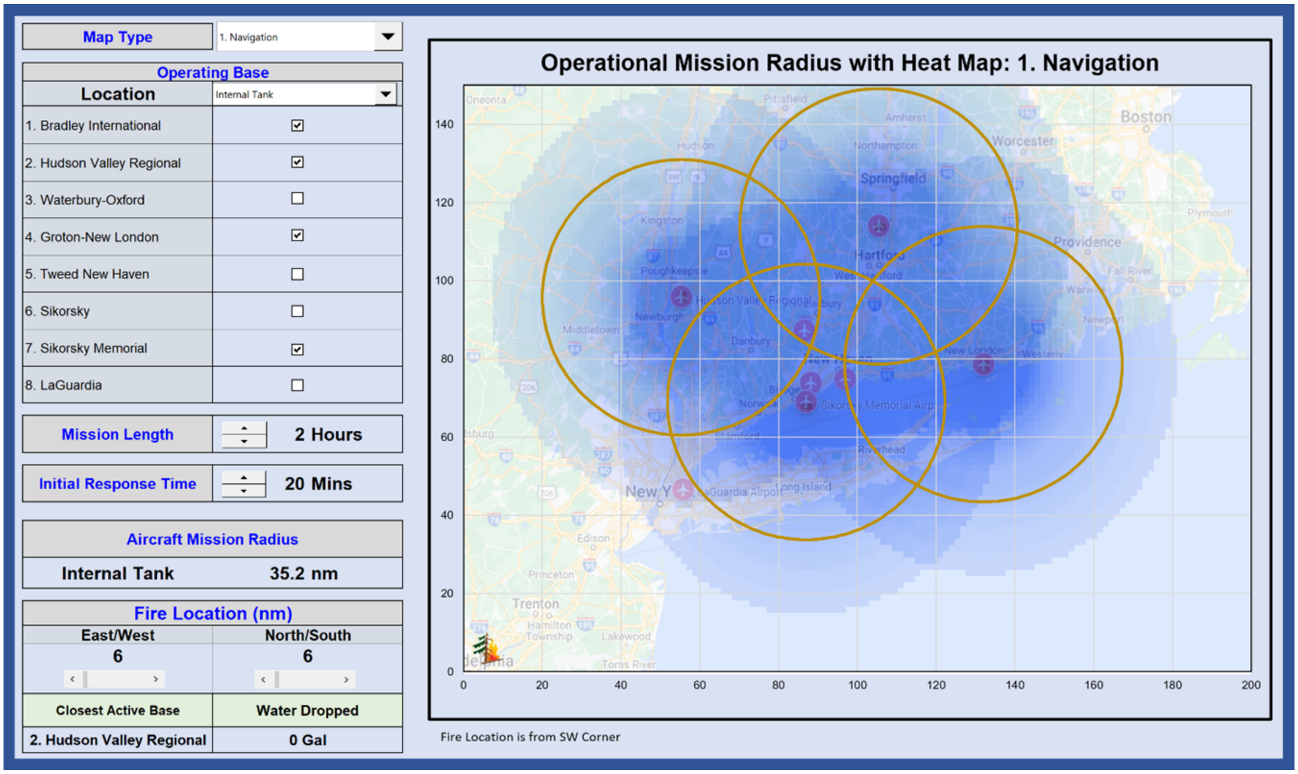

Figure 18. Mission radius model showing water delivery capability of four medium-lift helicopters using an internal tank; stationed at Bradley International, Hudson Valley, Groton-New London, & Sikorsky Memorial.

CONCLUSIONS

Each firefighting configuration has its benefits and limitations. However, the overall effectiveness in terms of water delivery to fire location in large part depends on the helicopter payload capability, airspeed, and availability of water source close to the fire location. There are three broad helicopter size classes based on helicopter weight that perform firefighting mission operations. Typically, the heavier the helicopter, the faster the speed on initial attack and the greater the amount of water that it can deliver to the fire locations. Multiple factors contribute to water delivery effectiveness such a tank type and capacity, helicopter performance, ambient conditions, and initial attack and mission distances. The firefighting helicopter comparison model discussed in this paper can evaluate various combinations of aircraft and water tank types to determine overall system effectiveness in the firefighting mission. Given the many helicopter and water tank type combinations possible as well as the range currently operating in the commercial space, analytical efforts are ongoing to identify the best and most effective helicopter based firefighting systems and how to best utilize the available resources today.

This analysis was intentionally limited in scope to understand the impact mainly due to water tank type. There are other relevant factors that were not specifically addressed in this paper including multi-role capability, maintenance and sustainment issues, individual platform design capability, night-time firefighting capability, and others. New capabilities to predict the spread of fires based on weather and empirical modeling using artificial intelligence to help direct aerial firefighting resources are expected to increase overall effectiveness as those capabilities are developed and employed by the industry. Technologies continue to develop improving the efficiency and effectiveness of firefighting operations.

In the end, the most critical factor in fighting wildfires is delivering water to the fire as fast and in as large quantity as possible. Each weather condition and geographic location may demand a specific capability to conduct firefighting operations most effectively. Maximizing the utilization of available firefighting helicopters with whichever tank type is available is essential to managing and extinguishing fires before they become widespread and cause significant damage to property and risk to life.

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ACKNOWLEDGEMENTS

We would like to thank David Peterson and Matthew Swisher for providing technical expertise in firefighting operations and Mike Cuppernull for his support of the development of this paper to the VFS Forum.

REFERENCES

[1] Bambi Bucket® is a registered trademark of SEI Industries Ltd.

[2] Harrod, Richy J. "Wildfire Trends in Washington." Washington Department of Natural Resources. 2015.

[3] Roedts II, Robert L., "The Bambi Bucket®: Evolution of the Most Versatile Aerial Firefighting Tool," Paper VFS-1178, 78th Annual Vertical Flight Society Forum Proceedings, Fort Worth, TX, 10-12 May 2022.

[4] "Bambi Bucket: Driven by Innovation." SEI Industries Ltd. 2021, https://www.sei-ind.com/wp-content/uploads/2020/12/Bambi_Bucket_2021.pdf.

[5] Copado, B.,"Festival Aereo de Gijon 2017." Wikimedia Commons, 2017, File:Festival Aereo de Gijon 2017 dsc 1165 36011910890 o (49070291783).jpg - Wikimedia Commons

[6] "FIREHAWK 1, Ready for Action," Kestral News; Aerial Firefighting, dated Feb. 4, 2021, https://img1.wsimg.com/isteam/ip/24914bf7-5b8a-4c6e-be73-accc23c39396/N125FH%20Kestrel%20UH-60%2058%20(1%20of%201).jpg/:/rs=w:1280

[7] "CAL FIRE Photo United Rotorcraft," Lockheed Martin Corporation, CAL-FIRE-Firehawk-Photo-United-Rotorcraft1.jpg (800×600) (lockheedmartin.com).

[8] "Extended Helitak Accordion Tank," Helitak Fire Fighting Equipment Pty Ltd, https://www.helitak.com.au/

[9] "Collapsed Helitak Accordion Tank," Helitak Fire Fighting Equipment Pty Ltd, https://www.helitak.com.au/

[10] "Helitak Firefighting Equipment." Helitak Fire Fighting Equipment Pty Ltd. 2022. https://helitak.com.au/.

[11] Guldimann, S., "69 Bravo Upgrades," Topanga New Times, dated Oct. 23, 2020, https://topanganewtimes.com/2020/10/23/69-bravo-upgrades/.

[12] "69 Bravo Helistop," https://69bravo.com

[13] HeloPod® is a registered trademark of ThinkPod, Inc.

[14] "HeloPod® The First Tactical Helicopter Dip Source and Cistern." Pump-Pod USA, 2020. http://pumppodusa.com/helopod/.

[15] "CAL FIRE FireHawk hovering over a HeloPod," HeloPod®, http://pumppodusa.com

[16] "Heli-Hydrant Fire Protection Tanks: A Hydrant for Helicopters." Superior Tank Company, Inc. 2022. https://superiortank.com/industries/fire-protection-storage/heli-hydrant/.

[17] "Orange County Fire Authority Helicopter hovering over Heli-Hydrant," Superior Tank Company, Inc. ®, https://superiortank.com/industries/fire-protection-storage/heli-hydrant/