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Methods to Rapidly Load and Effectively Dispense Firefighting Retardant for Firefighting Aircraft

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Methods to Rapidly Load and Effectively Dispense Fire Retardant for Firefighting Aircraft

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Speed and efficiency are crucial in emergency response, and aerial firefighting is no different. Firefighting aircraft must be able to collect and distribute retardant quickly, while ensuring the delivery is effective, in order to give ground crews more time to respond to the fire. If the retardant diffuses before it reaches the fire, or if too little is dropped, the efforts are unsuccessful and it will take longer for the fire to be doused, risking further damage to property or structures. The size and intensity of the fire also affects the type of aircraft and retardant used. Helicopters and single engine airtankers are commonly used for small, intense fires, while larger fixed-wing aircraft are used for large, fast burning fires. This paper investigated and compared various aircraft and their methods of filling retardant tanks, as well as dispersing the retardant. Scenarios with different refill methods, drop methods, cost and types of retardant were researched and charted to determine the fastest and most efficient method of loading and unloading retardant for different types of aircraft and wildfires.

I. Introduction

Over the last 70 years, aerial firefighting has become a more prominent component in wildfire prevention. After World War II, there was a surplus of military planes, which the U.S. Forest Service rigged with water to suppress fires [1]. These aircraft were the initial provisions in aiding ground crews to safely prevent wildfires from becoming larger and more destructive.

Like all first responders, firefighting aircraft must be able to respond to fire calls quickly and efficiently. Part of this involves the aircraft's retardant tanks to be refilled quickly. Currently, retardant tanks can be refilled between 8 and 30 minutes, depending on the size and number of tanks [2]. A higher refill rate will enable firefighters to return to the fire faster, providing that quicker response time. The amount and types of aircraft sent on the initial attack on a wildfire depends upon the location of the fire, the fuels in the area (vegetation, timber, structures, etc.) and current weather conditions. Once in the air, the retardant has to be dropped at a speed and altitude such that the retardant effectively covers the area below. According to an article from Airline Reporter, in order for retardant to be effective, pilots must drop it at about 150 ft AGL and between 120-130 MPH [3]. If the pilots fly too high or too slow, the retardant will diffuse into a useless mist before reaching the ground. Conversely, if they fly too fast or too low, the retardant will not spread far enough and will not completely cover the area, allowing the fire to burn through the line [3].

There are several other factors that contribute to the effectiveness of the retardant drop. Such factors include volume of liquid released, fluid type, flow rate from the tank, wind speed and direction, external temperature and humidity, topography, and pilot proficiency. There are also different methods to fight a fire, based on its size and the types of fuel in the area. A direct attack is a method, where retardant is dropped directly on the fire or around its perimeter. The flames may be doused by water, retardant, a fire-line, or even a wet-line that can be set along the edge of the fire to stop it from spreading. This approach is most effective on low intensity fires, usually performed by single engine airtankers (SEATs) or helicopters that carry 200-1000 gallons. An indirect attack builds the fire-line much further from the fire-edge, anticipating the fire's movement and giving ground crews more time to reach the fire and get the burn under control. This is usually done for large, hot or fast moving fires, using large airtankers (VLATs) that carry at least 1500 gallons. This paper will compare different tank capacities, various retardants and the effect of the refill/drop rates on the aircraft response and different types of fires.

II. Aircraft Comparison

Many firefighting aircraft currently in use are modified commercial or military airframes, initially designed for a different purpose. For firefighting, retardant tanks and dispersion systems must be integrated into different types of

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aircraft, For some aircraft, this involves structural modifications, which could lead to compromises in the mission. This section compares re-purposed aircraft, and how their original design differs from how they are used for firefighting.

A. Helicopters

Most helicopters were initially designed for military purposes, including personnel and cargo transport. In firefighting, helicopters are also used to transport firefighters and equipment, but they can also be used in direct attacks on the fire. Helicopters are grouped into three main sizes, typically carrying less than 1,000 gallons, and are commonly used in areas where larger airtankers cannot operate [4].

Type 1 helicopters are larger helicopters, like Chinooks (shown in Figure 1), and carry around 700 gallons of water, in a bucket or an internal tank with a snorkel, allowing the helicopter to refill in nearby bodies of water [4]. Some Type 1 helicopters can transport up to 15 people, but not while delivering retardant. Type 2 helicopters are medium-sized helicopters that can carry 300 gallons of water, either by bucket (Figure 2) or external tank (Figure 3). Although they don't transport as much retardant, they can transport firefighters or equipment easier than Type 1 helicopters. Type 3 helicopters are the smallest helicopter, able to carry up to 180 gallons by bucket and four to five firefighters. They have a faster cruise speed than the other helicopters, which means they can deliver personnel or aerial support to the fires faster. In addition to direct attacks, Type 3 helicopters can also be used as reconnaissance aircraft, to better determine what aircraft would be most useful [5]. As previously mentioned, these types of aircraft are able to hover and refill their buckets (or snorkel tanks) from local water sources. This allows the aircraft to return to the fires quicker, only going back to base to refill, change pilots, or pick up more firefighters and equipment. However, due to their size and strength, they are not able to carry as much as large airtankers, so the support they provide is usually limited.

Fig. 1 Type 1 Helicopter: Chinook [6]

Fig. 2 Type 2 Helicopter with Bucket Attachment [7]

Fig. 3 Type 2 Helicopter with External Tank and Snorkel [5]

B. Fixed-Wing Airtankers

As previously mentioned, many airtankers were designed as military planes and re-purposed for firefighting. Larger airtankers were initially built to carry large amounts of cargo for long endurance missions. Although these planes can still be used to transport equipment for firefighting, large airtankers can also be equipped with tanks that hold between 2,000 and 4,000 gallons of retardant. The C-130s (shown in Figure 4) use internal, self-contained firefighting units, most commonly the Modular Airborne FireFighting Systems (MAFFS), which are designed to be rolled into the back of the aircraft. They are comprised of pressurized tanks which hold a total of 3,000 gallons, a pressure system, and a nozzle that goes on to the paratrooper door for retardant dispersion [8]. The pressurization of the tanks controls the retardant drop speed and volume, allowing different levels of coverage or multi-drop capability. More on this will be discussed in Section IV. Other large airtankers, like the P3-Orion (shown in Figure 5), have external tanks with a constant/variable flow computer-controlled door system [4]. Similar to the MAFFS, the doors control the flow and volume of the retardant leaving the tank, allowing different coverage levels and wet-line lengths. Large airtankers are most effective in indirect attacks, as they can drop a large amount of retardant to build a strong wet-line, and give ground troops more time to respond to the fire. They are also useful in breaking up large fires and slowing the spread of a fast moving fire.

Fig. 4 Lockheed C-130 Airtanker [9]

Fig. 5 P3 Orion Airtanker [10]

C. Very Large Airtankers

Similar to large airtankers, Very Large Airtankers (VLATs) are re-purposed commercial aircraft with tanks added to the aircraft [5]. The two most common VLATs are the DC-10 and the Boeing 747 "Supersoaker", shown in Figures 6 and 7, respectively. The DC-10 is equipped with three gravity-fed, external tanks, with a total capacity of about 12,000 gallons. These tanks can be hooked onto the belly of the plane and removed for cargo transport. The Supersoaker is much larger, with two sets of five internal tanks, and a pressurized release system, and can hold a total of 19,200 gallons [11]. These tanks are removable, however, since they are so large, it takes a long time, so they are not removed frequently.

VLATs are most commonly used in indirect attacks, creating a long and wide wetline with varying amounts of coverage. They are also able to drop multiple loads, which allows several wetlines to be made in different locations. A VLAT will fly with a team of smaller aircraft that guides it to the drop area, then demonstrate where to drop the retardant. Since they can carry much more than other airtankers, usually only one is deployed.

Fig. 6 Boeing 747 Supersoaker [12]

Fig. 7 DC-10 as a Firefighting Aircraft [13]

D. Amphibious Aircraft

Unlike other firefighting aircraft, amphibious aircraft, or 'scoopers' can land on and refill from large water sources [5]. These types of aircraft vary, between small sea planes and large amphibious aircraft [14]. Smaller single engine airtankers (SEATs), like that shown in Figure 9, usually have external tanks fitted to the floats of the aircraft, or internal tanks located inside the floats [14]. They can carry about 800 gallons of water, and are usually used in coordinated flight groups with other small water bombers. They are ideal for fires with lighter fuels, such as grasses and brush, since they can quickly reach the fire and prevent it from spreading faster. Larger amphibious aircraft usually have a lower central fuselage, where the water tanks are contained, and wing tip floats to balance the aircraft in water [15]. These aircraft can hold between 1300-1600 gallons of water. They can last up to three hours before needing to refuel, typically dropping nine tank loads (about 12,000-14,400 gallons) within this time [16]. In addition to dropping regular water, some amphibious aircraft can mix a chemical powder with water and drop foam retardant. This is beneficial since foam provides a longer solution than water. More on this will be discussed in Section IV.

Fig. 8 Amphibious Plane: Bombardier 415 [17]

Fig. 9 Single Engine Airtanker: Firecatcher F-45 [18]

Amphibious aircraft refill by skimming the surface of a body of water. Some scoopers, such as the Bombardier 415 (shown in Figure 8), open a door directly to the tanks, and can refill in 12 seconds from sources that are 6.5 feet deep and 300 feet wide [19]. SEATs may also have a door, or they can release a scooping tube to siphon water to the tanks, like some helicopters [14]. Because of their ability to refill from nearby sources, amphibious aircraft only need to return to base to refuel, thus their turnaround time is much quicker than large airtankers, or aircraft that use chemical retardants. Scoopers are commonly used in direct attacks, dropping water directly on the fire to cool down the fire temperature or to stop fire edges from crossing firelines. Some aircraft have a separate door to release the water. These doors are usually hydraulic to drop the water as quickly as possible, or if there are multiple drop doors, simultaneously to avoid destabilization of the aircraft.

III. Refilling Retardant

One factor that contributes to a decreased response time is how quickly the retardant tanks are refilled. The Interagency Airtanker Board (IAB) requires that all retardant tanks, "shall be capable of being filled in conformity with the approved retardant load at an average fill of not less than 500 gpm when filling through only one fill port" as stated in Section VII, Subsection A, Item 3b of the IAB Procedures and Criteria [20]. For some of the larger airtankers, this could be between 15 and 20 minutes to refill the retardant, not including the time it takes to refuel.

As previously discussed, some helicopters are able to siphon water from natural sources, and can be fully refilled in a couple seconds [5]. Most of these systems currently in use are able to gather water at rates ranging from 450 to 1,056 US gallons per minute. A new system developed by Spanish firm Inventec, however, is claimed to be capable of sucking up 264 gallons in just five seconds – that scales to a rate of 3,170 gallons per minute [21]. This technique is not common for airtankers, as it typically requires the aircraft to hover over the body of water. However, there are aircraft that have been developed to scoop water from nearby sources. These aircraft can hold up to 1,600 gallons and refill in 12 seconds from sources that are 6.5 feet deep and 300 feet wide [19]. This roughly translates to a refill rate of about 8,000 gallons per minute. Figure 10 below compares the maximum capacity of various aircraft versus the time it takes to refill.

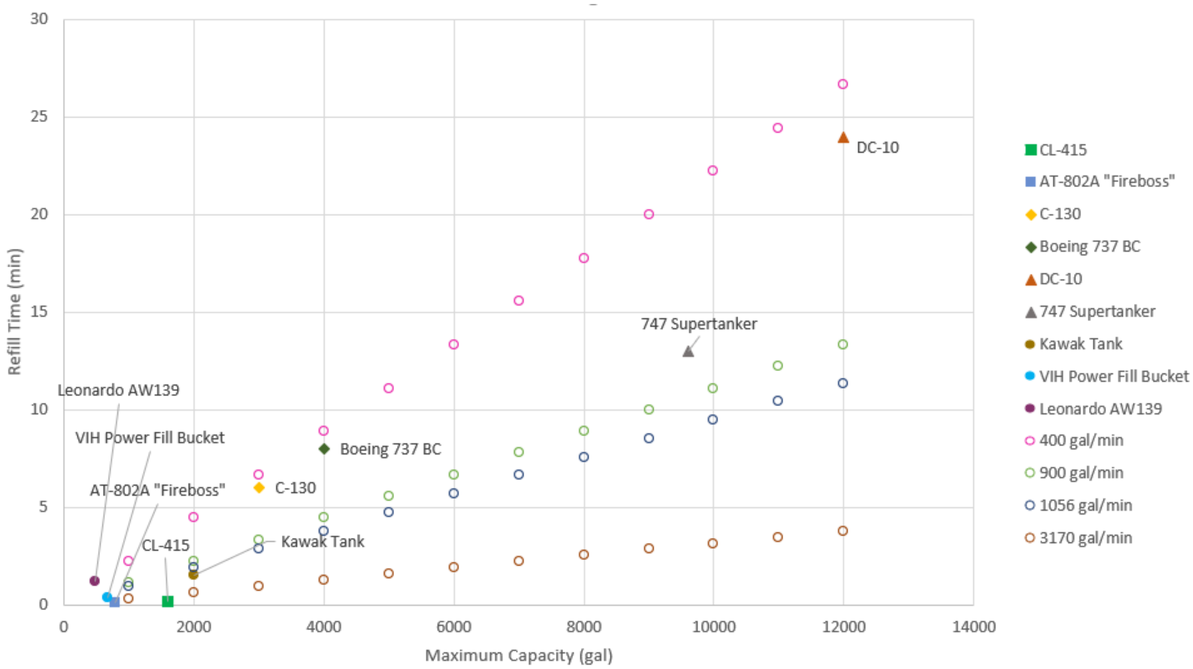

Fig. 10 Maximum Capacity vs Total Time to Refill Retardant

Each of the different types of aircraft previously discussed are used for comparison, and are distinguished by different symbols. The squares represent scooping aircraft, diamonds represent large airtankers, triangles represent VLATs, and solid circles represent helicopters. The unfilled circles all represent different rates of water siphoning at capacities ranging from 1,000 gallons to 12,000 gallons. As previously mentioned, this method is not used on large airtankers or VLATs, however similar capacities are shown for those rates for comparison. It should also be noted that half of the Supertanker's capacity is shown, as both sets of tanks can be refilled simultaneously [11]. Some aircraft had specified refill rates, such as the Supertanker or the helicopters. For the aircraft that did not have stated refill rates, the capacity of the tanks were multiplied by the IAB required rate of 500 gallons per minute, to calculate the total refill time.

Most of the aircraft can refill their tanks in under 15 minutes, except for the DC-10 and helicopters with a capacity of more than 7,000 gallons, and a 400 gallon per minute pump rate. Since these rates only reflect those capacities, the quickest relative refill time isn't easily defined. Additionally, although most of the aircraft use water as a retardant, large airtankers and VLATs typically use a chemical retardant. The different fluid densities affect the flow rate; the higher the density, the more viscous the fluid, and thus the lower its flow rate. The researched rates are mostly assumed to be water, however for the airtankers, it is assumed to be retardant with a density of 9 pounds per gallon [3]. To better compare the different rates for different fluids, each of the rates were converted with respect to both water and retardant using Equation 1, where Q is the flow rate of the fluid, and ρ is the density. For rates that were given with respect to the desired fluid, nothing changed.

$$Q_{retardant} * \rho_{retardant} = Q_{water} * \rho_{water} \quad (1)$$

Once the converted rates were found, it was then assumed that those various rates would be used to fill a tank with a set capacity. This would put all the rates from Figure 10 on the same level. The chosen capacities were 1,000, 5,000 and 12,000 gallons. To find the total rate to refill, the capacity was divided by the flow rate, and is graphed in Figure 11. Some of the aircraft have the same rates, since they used the IAB minimum required rate, so duplicates were removed for the comparison.

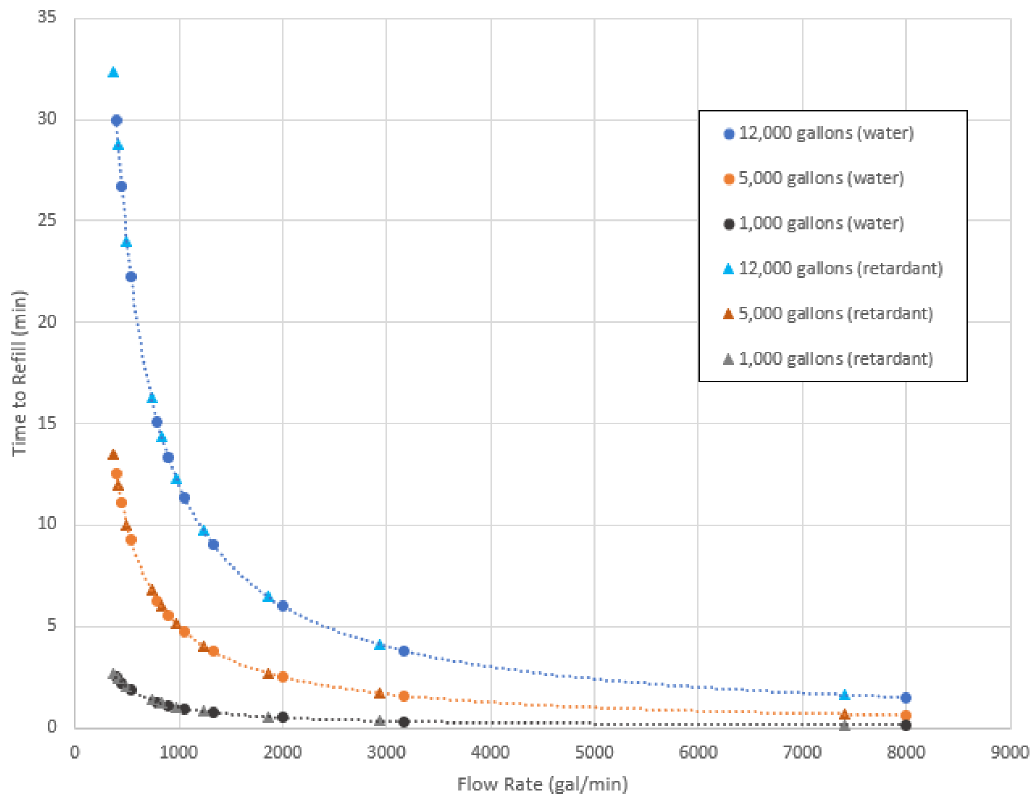

Fig. 11 Flow Rate vs Time to Refill

The various trendlines show that, regardless of the type of fluid, as the rate of flow increases, the total refill time decreases, more significantly for larger capacities. For a 1,000 gallon capacity tank at any refill rate and either fluid, the total time to refill the tanks is less than 5 minutes, and changes very little as the flow rate increases. However, for the 12,000 gallon capacity tank, the change is very drastic for flow rates less than 2,000 gallons per minute, going from over 30 minutes, to almost 5 minutes. This reflects that at lower flow rates, for larger tanks, it will take much longer to refill.

Additionally, most aircraft carry less than 5,000 gallons. Based on the chart, at any flow rate for either retardant, the aircraft will fill in less than 15 minutes. The figure also shows that with the IAB required rate of 500 gallons per minute, the total refill time is less than 25 minutes for any capacity. Most of the higher rates are from the helicopters and scoopers, since they can collect a large volume of water in a short span of time. Airtankers, on the other hand, must use the retardant refill systems provided at bases and airports, which use tubes with a much smaller opening, thus limiting the flow rate [20]. As previously mentioned, the chemical retardant has a higher density, so its flow rate is lower than that of water. The lower flow rate means it will take longer to fill the tanks, as also shown in the figure.

IV. Retardant Dispersion

As previously mentioned, the effectiveness of the retardant once it is dropped depends on several factors. Disregarding pilot proficiency and environmental factors, the ground pattern is greatly influenced by the retardant's fluid properties, such as flow rate, volume, and flow characteristics [22]. Tank geometry, size, and internal baffling also affect the flow characteristics of the retardant, but the size will be the factor most reviewed in this paper. This section compares different types of retardants, the tanks of various aircraft, and those factors impact the coverage levels.

A. Retardant Types and Effects

Much like the different aircraft, there are several types of retardants used in firefighting for various purposes. The four main retardants used are long-term retardants, gels, foams and water. Water is one of the most common retardants, since it is easily accessible and much less expensive than chemical retardants. It is most commonly used in direct attacks to lower the temperature or intensity of the fire. Water is rarely used for indirect attacks, since once it evaporates, it becomes ineffective.

Long-term retardants alters fuel decomposition to slow or stop the burn. These retardants are also not dependent on water, so they will remain effective until removed from the area applied [23]. However, since it does not rely on water, the aircraft must return to base or an airfield to refill. This is typically used to set up a wetline in indirect attacks, but can also be used long before a fire reaches an area, to protect buildings or property from being consumed.

Gels are added to water to enhance its effectiveness; it causes water to better adhere to surfaces, has a higher heat absorbing capacity, and reduces evaporation impacts [23]. However, since gels are used with water, once the water evaporates, the retardant will become ineffective. Gels are most common in structure protection, due to the moderately lasting effects. It can also be used for indirect attacks, however, it is not as effective as long-term retardants.

Foams are also combined with water to slow evaporation, increase its insulating capacity, and allow it to better penetrate into fuels [23]. Just like gels, once the water evaporates, the foam is not as effective. This retardant is mostly used in direct attacks and to prevent re-ignition after the fire is put out. Some scoopers have the ability to mix foam onboard after they pick up water [5]. This further mitigates the turnaround time, allowing the aircraft to stay near the fire, pick up water, and make foam if the fire grows stronger or spreads faster than anticipated.

The ground patterns of the retardant are affected by its fluid properties, mostly the flow rate leaving the aircraft. Much like the flow into the tank, a higher density fluid means a lower flow rate. With less fluid leaving the tank at a given time, less of the area is covered, and thus the drop is not as effective. Conversely, if the fluid leaves the tank too quickly, it diffuses too soon and is also rendered ineffective [22]. The foams, gels, and long-term retardants have components that thicken water, increasing its viscosity to keep the water from turning into a mist and allowing it to stick to the fuel. The weight of the retardant, however, does not affect the drop speed or how much the liquid drifts when dispersed, due to the effects of gravity.

B. Emergency Drop and Drop Requirements

In addition to the flow rate requirements for refilling retardant, the IAB also has requirements for dropping retardant. For scoopers and SEATs, the flow rates for retardant systems must be at least 400 gallons per second ([20], Section 2, Subsection E, Item 1 and Section 4, Subsection D, Item 1). Only Type 1 helicopters have listed requirements, since they can have internal or external tanks, whereas buckets are not considered. Type 1 helicopters and airtankers also share the same requirements for their tank system criteria, since they typically carry more than 1,000 gallons. For external performance, it is required that all tank systems have the ability to apply a continuous ground pattern at a selected coverage level for any volume ([20], Section VII, Subsection B, Item 8a). Also, based on the volume being dropped, the IAB sets a minimum length of the wetline for every 100 gallons and varying coverage levels. This is especially important when building wetlines to ensure that there is nowhere for the fire to pass through.

Airtankers and Type 1 helicopters must also be capable of making multiple equal volume releases based on their maximum capacity ([20], Section VII, Subsection B, Item 9a). This requirement allows 2-8 retardant drops over different areas, which means the aircraft can perform various attacks to combat different types of fires. Additionally, no aircraft shall release less than 200 gallons for any drop ([20], Section VII, Subsection B, Item 9a). This requirement does not apply to SEATs, amphibious aircraft or helicopters using buckets, since their total capacity does not usually exceed 200 gallons. In emergency situations, the entire load must be able to be dropped in 6 seconds or the maximum delivery flow rate, whichever is longer. The requirement also states to use gravity-fed evacuation if it is determined that pressurized release could cause adverse flight characteristics in an emergency ([20], Section VII, Subsection A, Item 2). This release rate, although fast, is not as effective for fire suppression, since less of the area will be covered.

C. Ground Pattern Comparison

Before these aircraft can enter the field, they must run tests to be sure that their coverage meets all of the requirements. These tests are run by setting up hundreds of cups in a rectangular, grid pattern, then airtankers fly over the grid and drop retardant. This test primarily determines how much area is covered as well as the coverage level of the spread [22]. Figure 12 compares the drop pattern characteristics of eight different aerial firefighting aircraft with different drop methods evaluated by the IAB. The different levels of coverage are based on the number of gallons per 100 square feet (gpc). For example, a level 2 coverage would be 2 gpc. In the figure, the darkest color represents the heaviest coverage, at level 8 [24].

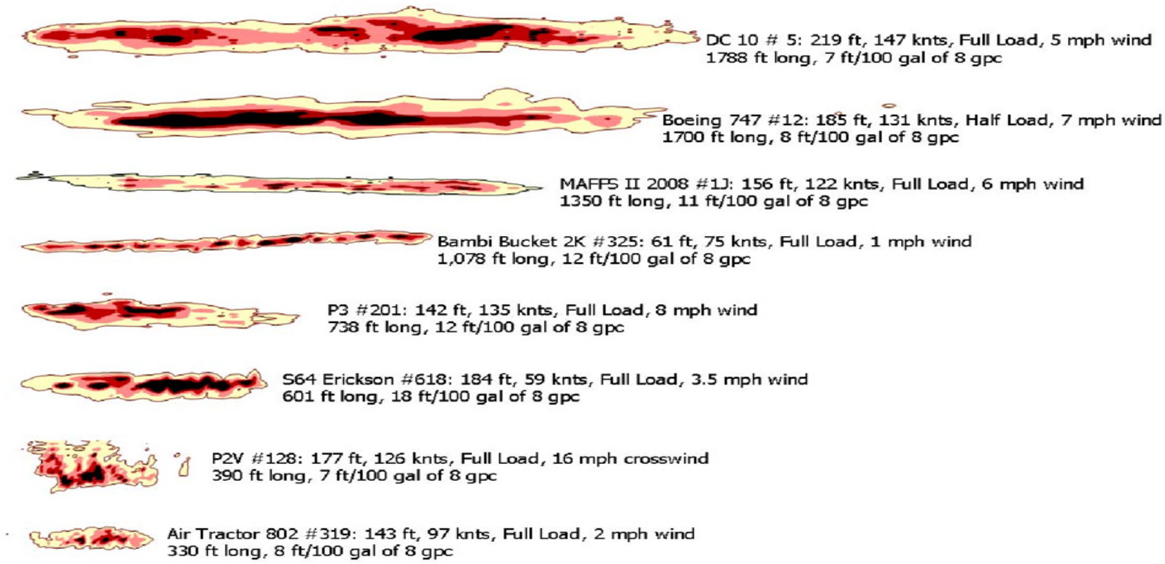

Fig. 12 Drop Pattern Comparisons [24]

Although the Boeing 747 only dropped half of its full load, it shows the most uniform and dense drop pattern, most likely due to the pressurized release system providing a constant flow rate from the aircraft. The MAFFS II units are also pressurized, however, they don't have as dense of coverage as the 747, and the ground pattern is not as consistent. The DC-10 is gravity fed, so there are several inconsistencies throughout the drop. Compared to the 747 and the MAFFS II, the DC-10 has more dense coverage earlier in the drop. This means as soon as the retardant is released, the area will be covered by the desired amount, which better prevents the growth of the fire. Surprisingly, the Bambi Bucket used by helicopters shows a fairly uniform ground pattern with a dense coverage early in the drop. The P2V has a wide, spotty coverage, possibly caused by the 16mph crosswind during the test. However, even with the uneven drop pattern, some areas still had a level 8 coverage. The S64 Erickson is a Type 1 helicopter, and although it doesn't carry as much as the larger airtankers, it also provides a dense coverage, with the second half of the drop having a consistent level 8 coverage. An interesting study would be to see what percentage of the drop area has a particular coverage level based on the aircraft, however, this would require data from drop tests.

V. Cost Comparison

Although tank capacity, drop efficiency and effectiveness, and aircraft speed and endurance are incentives to use certain types of aircraft, the cost is also an important factor. The purchase price, operating costs, hourly rates, aircraft availability and the cost of retardant must all be considered to determine which aircraft is best suited and affordable for different fires.

The daily operating costs and hourly rates of various aircraft were obtained from Source [25]. The initial cost was added to the daily rate, which was eight times the hourly rate, assuming an eight hour day. The cost of retardant used per hour was calculated by multiplying the number of times the aircraft refills per hour by the maximum tank capacity, then multiplying that by the cost of retardant, about \$3.10 per gallon [26]. This hourly retardant cost was multiplied by eight, assuming an eight hour day, then added to the total daily operating costs to get the total overall cost. Figure 13 compares the capacity of various aircraft with their total daily costs.

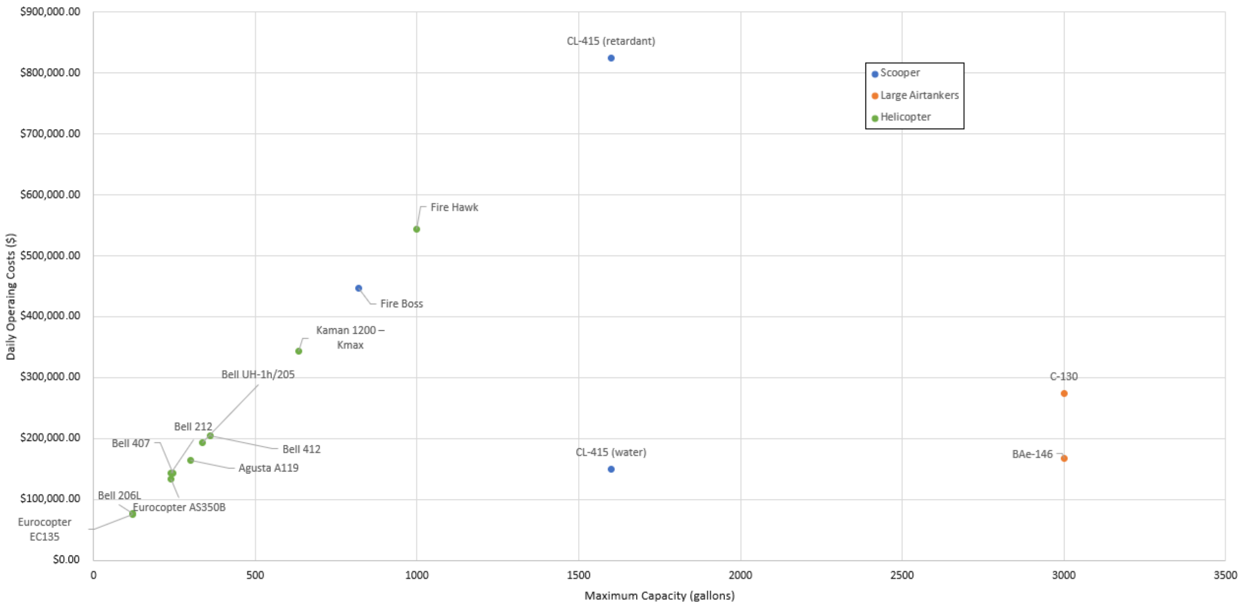

Fig. 13 Cost per Day vs Maximum Capacity

Because of their large capacity, VLATs cost about $65,000 per drop, plus an additional $22,000 per hour in flight time [26]. To better show the relationship of the lower capacity aircraft, VLATs were purposefully excluded from the figure. For the helicopters, as capacity increases, the cost also increases linearly. However, the large airtankers appear to have a much lower operating cost than some of the helicopters and both of the amphibious aircraft. This is most likely due to the low daily operating costs. The aircraft's fire suppression systems are also excluded in the analysis, so aircraft with removable tanks, like the C-130, may still cost more than a helicopter with a bucket attachment. Also, the fluid is assumed to be retardant, as it is much more expensive than water, so aircraft that use water more than retardant will likely be much cheaper to operate than pictured.

Excluding the cost of converting the aircraft for firefighting purposes, the initial purchase price follows a similar trend; the larger the capacity, the more it costs [25]. Table 1 shows the daily operating cost, purchase price and capacity of several aircraft.

Table 1 Costs of Firefighting Aircraft

Aircraft	Max Tank Capacity (gallons)	Total Cost per Day $	Purchase Price ($ millions)
747 Supertanker	19,200	726,160.00	80-120
DC-10	12,000	528,600.00	20
C-130	3,000	274,400.00	7-14
BAe-146	3,000	167,400.00	73
CL-415	1,600	150,000.00	30
Fire Hawk	1,000	543,264.00	26
Kaman 1200 - Kmax	635	343,960.00	8
Bell 412	360	204,360.00	9.6
Agusta A119	300	164,100.00	2.38
Bell 407	245	143,000.00	2.65
Eurocopter AS350B	240	133,000.00	1.85

As shown in the table, the 747 Supertanker is by far the most expensive plane. The daily operating costs are likely so high because of its large capacity. The next most expensive to purchase is the BAe-146, a large airtanker. It's daily operating costs, however, is much lower than that of a C-130, which holds the same volume. The CL-415 more expensive in the initail purchase, but because it uses water more than retardant, its daily operating costs are much lower. The daily costs of the helicopters are estimated with retardant being the fluid used, however, they are also more likely to use water, so their prices will be even lower. One thing to consider is that although the smaller aircraft are cheaper individually, they are usually used in groups [4]. This means that the daily cost of one C-130 is less than that of any two helicopters using retardant, and still carries much more. However, as previously mentioned, helicopters are better suited for specific fires that large airtankers might not be, so although a C-130 might be cheaper, it might not be the right aircraft for the job.

VI. Conclusion

Firefighting aircraft have become more prominent in fire suppression efforts by providing support to ground crews or putting out fires in hard to reach locations. The type of the aircraft that should be used in each incident greatly depends on the type and size of fire. For large, fast burning fires, large airtankers or VLATs should be used to set up a wetline with chemical retardant to prevent the fire from spreading past a certain area, which gives ground crews more time to reach the fire. Large airtankers and VLATs are also more expensive, but they can carry much more than smaller aircraft and are better suited for missions that require a lot of retardant. They are also capable of releasing retardant at different times and volumes, which is helpful when dealing with different fires in one area. Although they have a much larger capacity and greater coverage, their response is not as quick as smaller aircraft, and they are not able to reach areas with limited access, such as a valley. Helicopters and SEATs are better for small, intense fires since they do not need a large amount of retardant to reduce the fire. Additionally, their ability to refill from nearby sources further reduces their response time, which means they can continue their fire suppression efforts without needing to return to base, thus allowing ground crews more time to respond to the fire. This also reduces the cost, since water is cost-effective compared to retardant. However, chemical retardants are also preferred to water for long-term solutions, such as making wetlines and protecting structures. Using the most efficient type aircraft for a certain type of fire can greatly reduce the risk ground crews face, while also providing necessary support.

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