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Drone swarm technology as a competitive alternative to traditional aerial firefighting

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Abstract

Aerial firefighting is effective however very expensive solution to suppress forest fires. Drone application as a most developing branch of the aviation industry can be a complement, or perhaps even a competitive solution with the traditional aerial firefighting. Based on the input data drone swarm technology can be not just an effective but also an efficient solution suppressing forest fires. In this study author used both practical and theoretical approach to investigate the possibility of drone usage delivering suppressant to fire front. Firstly, the required width of wetting strip and the required amount of water per unique area were investigated; practical experience shows that based on the flame length first responders can estimate both the effective width of the fire brake and the amount of water required per a unique area. As a second part of this paper, the transport capability of a drone was investigated during its life cycle that is specially optimized for firefighting. In the example author took a 100 kg transport capacity that is easy to transfer to other drone design; in case of 0.3 MWm-1 fire intensity 100 kg water is enough to make 100 m long fire brake, in case of 3.4 MWm-1 fire intensity 100 kg water enough to create only 2.5 m fire brake. Even if this latest results can be seen a bit short we have to take into account the swarm technology. In 10 km distance 30 drones can built a 5 m long fire brake per a minute that means 300 m per hour. This result is no worse than what large or very large air tankers can built averagely in this fire intensity. Expecting the technological development in the near future the length of the fire brake will raise drastically meaning that drone swarm technology will be not a complement but a competitive solution to the traditional aerial firefighting.

1. Introduction

Due to climate change, forest fires are an increasingly serious problem in the developed world. Fires will become more frequent, more widespread, and more difficult moreover the suppression costs are raising very dynamically. One of the most effective, but certainly the most expensive ways to suppress fires is by using aircraft. In doing so, planes or helicopters release various extinguishing agents, especially water or retardants, at the burning front line. Drone applications, as the most dynamically developing branch of aviation (Tsiamis et al. 2019) raises the question of whether the use of drones makes sense, has a professional or an economic advantage in firefighting tactics. Attempts have been made to use drones for fire detection (Yandouzi 2022), surveillance (Alexis 2009, Kumar 2011), and even to ignite controlled fires (Goldammer et al. 2012), but the possibility of extinguishing large-scale front lines has been investigated very limited (Ghamry et al. 2017; Ausonio et al. 2021).

There are more and more literatures dealing with drone technology (Tsiamis et al. 2019) moreover the latest time appeared even videos and reports, mostly in the social media, presenting the possibility of drone technology in the fight with different kind of fires (Gabbert 2019; Steffen 2020; Tech Insider 2021; Aydin et al. 2019). Forest fire requires much more extinguishing material than closed area fires so the drone technology due to its limited transport capacity seems to be not reasonable for this purpose. However, the swarm technology might compensate the limited transport capacity of single drones. As an example, a large air tanker (LAT) carrying 12,000 litres suppressant to 100 kilometres and it can takes 2 circles per hour means that the flow rate is 400 litres per minute at the fire front. The distance that is 100 kilometres seems to be long in normal case however this value is normal in case of LAT service. The flow rate can be the same if a fire engine with 12,000 litres capacity transports water for 10 kilometres distance with 2 circles per hour frequency. The fire does not mind about how far the water comes from or how it gets there, the main condition for extinguishing the fire is the amount of water flow. At the current level of technology, one drone is assumed not to be able to provide an efficient flow of water, but with their mass application, that is swarm technology, this might be ensured even today. The purpose of this paper is to investigate the possibilities of drone swarm technology to suppress fires.

2. Methods

The author used the relevant literatures dealing with drone swarm technology and firefighting however there are only some that focusing specially on this topic (Ghamry et al. 2017; Ausonio et al. 2021). Therefore, this study uses some assumptions that is adapted basically from other technology and practical experiences however the data regarding forest fires calculating with comes from the practice that confirmed by literatures as fundamentals (Byram 1959; Bel 1986/87). The author used in this research even his practical experience in both the application of drones and the extinguishing of forest fires, and he used also simple mathematical methods and logical conclusions to present the results.

3. Results

Knowing or estimating the intensity of a fire is important to be able to calculate how much suppressant we need to extinguish it. Low fire intensities can be extinguished with fewer extinguishing agents, while in the case of a higher fire intensity, the maximum amount of suppressant that can be used is not enough. The minimum and maximum amount of extinguishing agent required for successful suppression is known from laboratory measurements and practical experiences. The minimum effective amount may vary depending on the literature, usually between 0.2 and 0.5 kgm^{-2}; in this study, the author calculates a value of 0.5 kgm^{-2}. The maximum amount of suppressant does not exceed 5 kgm^{-2}, even in a mature forest. Knowing the length of the flame is needed to determine the width of wetted strip in front of the front line. Based on practical experience, a wetted strip of 2 to 2.5 times the flame length effectively counteracts the thru-burn, i.e., it prevents the spread of fire. The lower width value is sufficient at lower fire intensities, the higher value is at higher fire intensities. In the study, the author calculates a 2-fold value.

Based on the above, we have to choose the amount of extinguishing agent required per unit area by the intensity of the fire or by the height of the flame. The minimum effective amount of water is 0.5 kgm^{-2} and the maximum is 5 kgm^{-2}. In the study, the amount of water that the author assumed is delivered to the fire front with the drone was 100 kg. Figure 1 shows the amount of water that is sufficient to wet this area as a function of fire intensity.

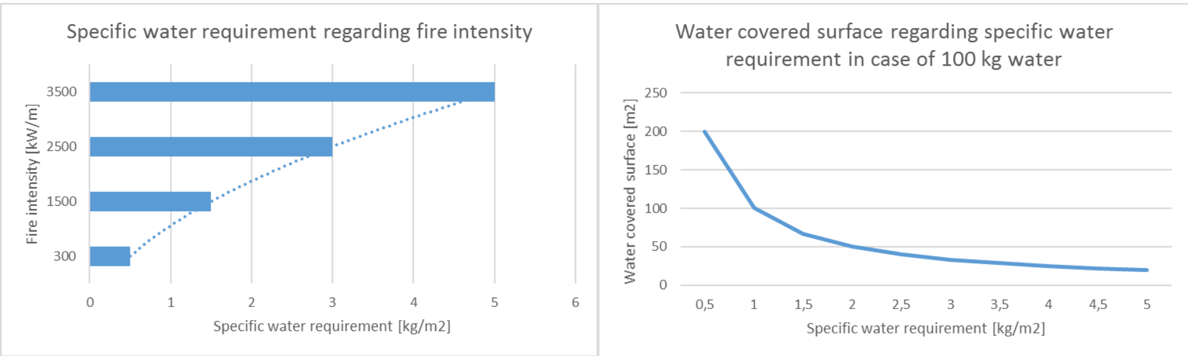

Figure 1. The amount of water that is sufficient to wet the area as a function of fire intensity (left) and the water covered surface depending on the specific water requirement (right)

The author assumed that the average life cycle of a drone optimized for firefighting is about 2,000 hours. It is possible if we count with the life cycles of brush less electric engines (Brando et al. 2022), that is a main critical part of the drone. The average speed during the service life is calculated with 80 kmh^{-1}, so the distance covered during the life cycle is about 160,000 km, in one half of which it carries a fire suppression materials to the fire front that can be water, short or long term retardants. In the other half of life cycle drone flies back to the charging station empty. The shape of the drone is aerodynamically optimized due to continuous long-range flights, so it also produces buoyancy with its surface design. This allows the specific energy consumption to be lower than e.g. at spray drones of the same power. When flying back, the weight of the drone is significantly less, so its flight speed can be higher than average, which can result in time savings that compensate for the loss of time caused by charging at the base and releasing time at the fire front. Using the above assumptions, the life cycle time is halved, so the transport time of the suppressants, as well as the return time is 1,000 to 1,000 hours. Besides the flight hours the time of suppressant release at the fire front and the refuelling time at the base site is considered negligible.

The load capacity of a drone developed for firefighting is assumed 100 kg. Based on this, the transport capacity of the drone is 8,000,000 kg.km (1000 h x 80 $km.h^{-1}$ x 100 kg) during its life cycle. This can be modified in the same way as the other data, following the logical principle of the calculations to obtain the efficiency characteristics for the given values.

Based on the first assumption (A), the distance between the refuelling base and the front line of the fire is taken to be 10 km on average. In this case, the drone can make 4 turns in 1 hour, so the delivered quantity is 400 kg. The distance and the delivered quantity are inversely proportional, i.e. the smaller the distance, the more the delivered quantity, and vice versa. Assuming individual cases, as the distance increases, the quantity that can be delivered decreases (200 kg per hour for 20 km) and increases as the distance decreases (800 kg per hour for 5 km). During the life cycle of the drone, that is about 2,000 hours, and taking four missions per hour cycle, 800,000 kg of suppressant can be applied at a distance of 10 km (2,000 h x 4 mission per hour x100 kg per mission). With this process at a distance of 5 km carried 1,600,000 kg water, at a distance of 1 km carried 8,000,000 kg water by only one drone. Based on the above we can multiply the transported value of the water depending on the number of the drones included in the swarm.

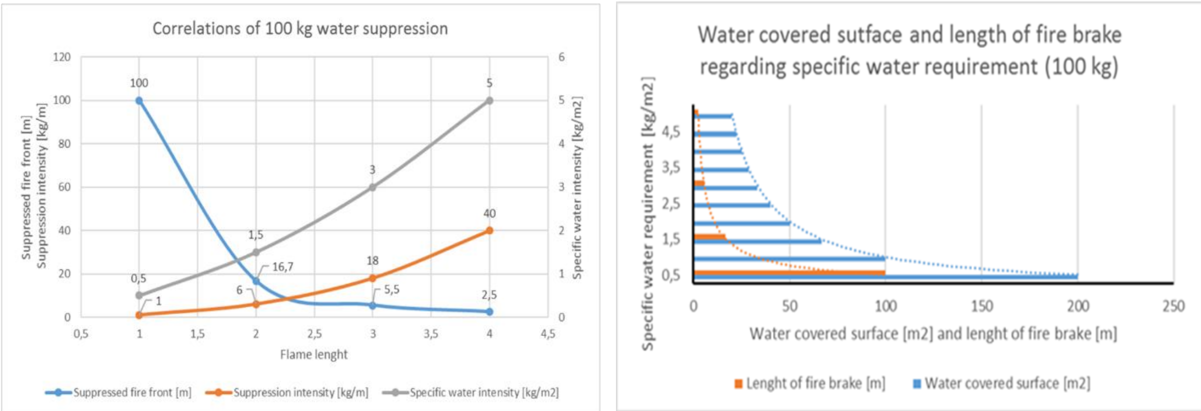

Figure 2. Different calculations of effectiveness with 100 kg water delivered by drone

4. Conclusions

Aerial firefighting is effective however very expensive solution to suppress forest fires. Drone application as a most developing branch of the aviation industry can be a complement, or perhaps even a competitive solution with the traditional aerial firefighting. Based on the input data drone swarm technology can be not just an effective but also an efficient solution suppressing forest fires. In the example author took a 100 kg transport capacity that is easy to transfer to other drone design; in case of 0.3 MWm^{-1} fire intensity 100 kg water is enough to make 100 m long fire brake, in case of 3.4 MWm^{-1} fire intensity 100 kg water enough to create only 2.5 m fire brake. Even if this latest results can be seen a bit short we have to take into account the swarm technology. In 10 km distance 30 drones can built a 5 m long fire brake per a minute, that means 300 m per hour. This result is no worse than what large or very large air tankers can built averagely in this fire intensity.

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