Firefighting Drone Water Bomber

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Introduction

Our capstone project investigates the feasibility of using a drone fleet to combat wildfires through conceptual design and strategy optimization.

In order to achieve our goal, we had three main objectives.

1. Researching aircrafts, wildfires, and meeting with BC Wildfire Services to understand the roles and limitations of using drones to fight wildfires.

2. Develop a detailed strategy for fighting wildfires with drones, using computer simulations to model wildfire spread and effective responses.

3. Create a conceptual design of the drone, using a genetic algorithm to mimic natural selection and determine the best drone parameters. The conceptual design is modelled using 3D CAD software (SolidWorks).

These objectives are aimed to tackle the first two elements of the system engineering process, as shown in Figure 1 below.

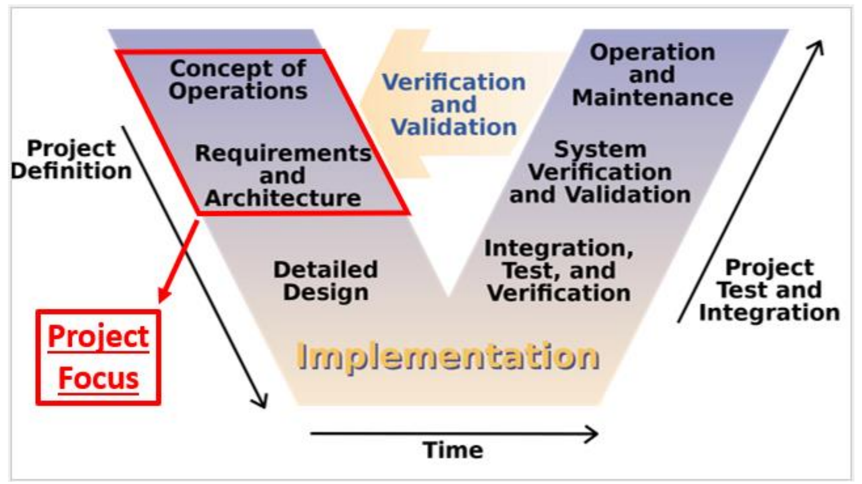

Figure 1: System Engineering Process [1]

Background

Currently, human crews either on the ground or with aircrafts are the main way to fight wildfires. However, this poses a large risk to these individuals. Regarding drones in firefighting, they are only used in fire detection, fire monitoring and mapping, and directing ground crews safely at the moment.

Table 1 below lists several important wildfire statistics.

Table 1: Annual Wildfire Statistics

British Columbia Wildfire Annual Averages (2010-2020) [2]	
Wildfire Occurrences	1352
Hectares Burned	348,917
Cost to Government	$265.3 million

Main Firefighting Strategies

Direct Attack [3]
Water directly applied to fire
Physical fuel removal

Indirect Attack [4]
Remove fuel in front of fire
Use water and/or fire retardant

Genetic Algorithm and Parameter Optimization

To complete the engineering design of the drone, different input parameters were investigated, including water payload, lake size and wing specifications (Figure 2). With our inputs, there were 30,000,000,000 possible combinations, and so a genetic algorithm was used to optimize these values for a desired set of iterations.

The genetic algorithm works by mimicking natural selection, so that only the best solutions are kept for every iteration and eventually an optimal design is found.

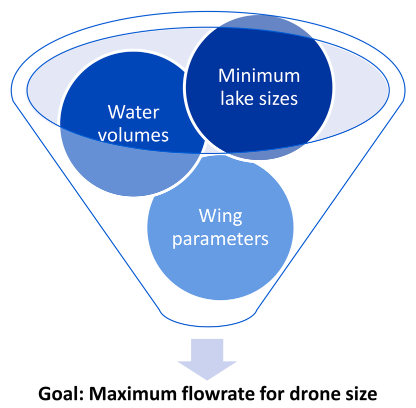

Figure 2: Genetic Algorithm Input Parameters

Figure 3 shows the pareto front created with multi objective genetic algorithm optimization to minimize drone mass and maximize flowrate. The two extremes are at the bottom right (0 kg) and top left (47 L/s). Figure 4 was then used to determine a combination of flowrate and mass. As seen, there is a plateau of flowrate per unit mass (blue) just before 10,000 kg indicating that along this range the flowrate does not change with mass. Wingspan was also plotted (black) with change in mass to observe changes in size. Either extreme of the plateau indicates the largest (right) and smallest (left) drone size to meet an equivalent flow rate. To leverage the benefits of drones, the smallest size was selected.

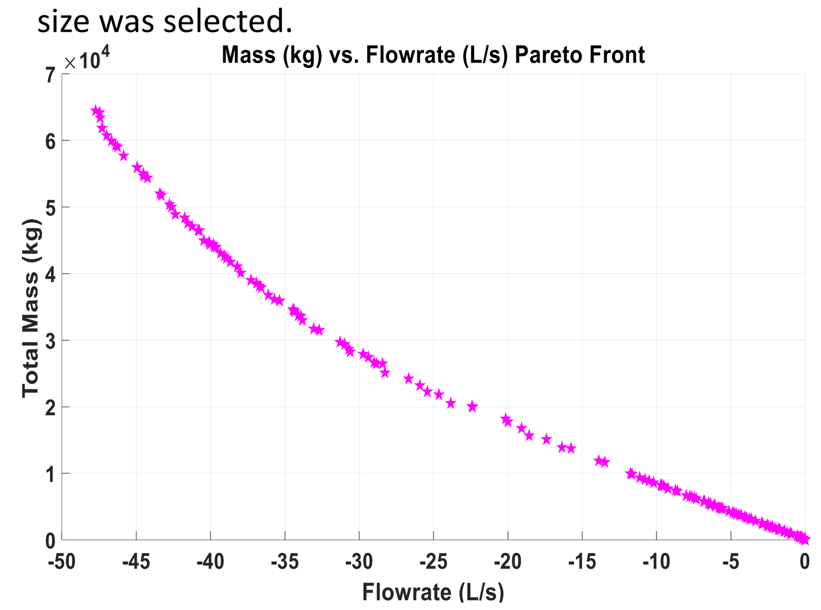

Figure 3: Pareto Front Showing Optimization of Competing Parameters (Mass and Flowrate)

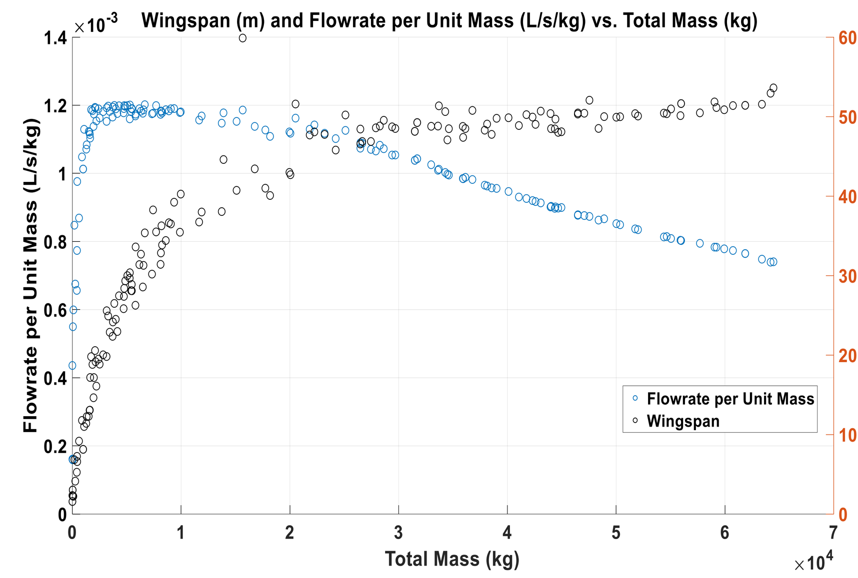

Figure 4: Optimization of Wingspan and Flowrate per Unit Mass

Final CAD Model

The CAD model for our drone is inspired by the CL-415 Water Bomber and was designed on SolidWorks. In addition to typical aircraft components, this model features a retractable water scooping mechanism, hatches for water deployment, and a cruciform tail design. This design maximizes flying stability through turbulent airspace and the ability to quickly recover from any spins.

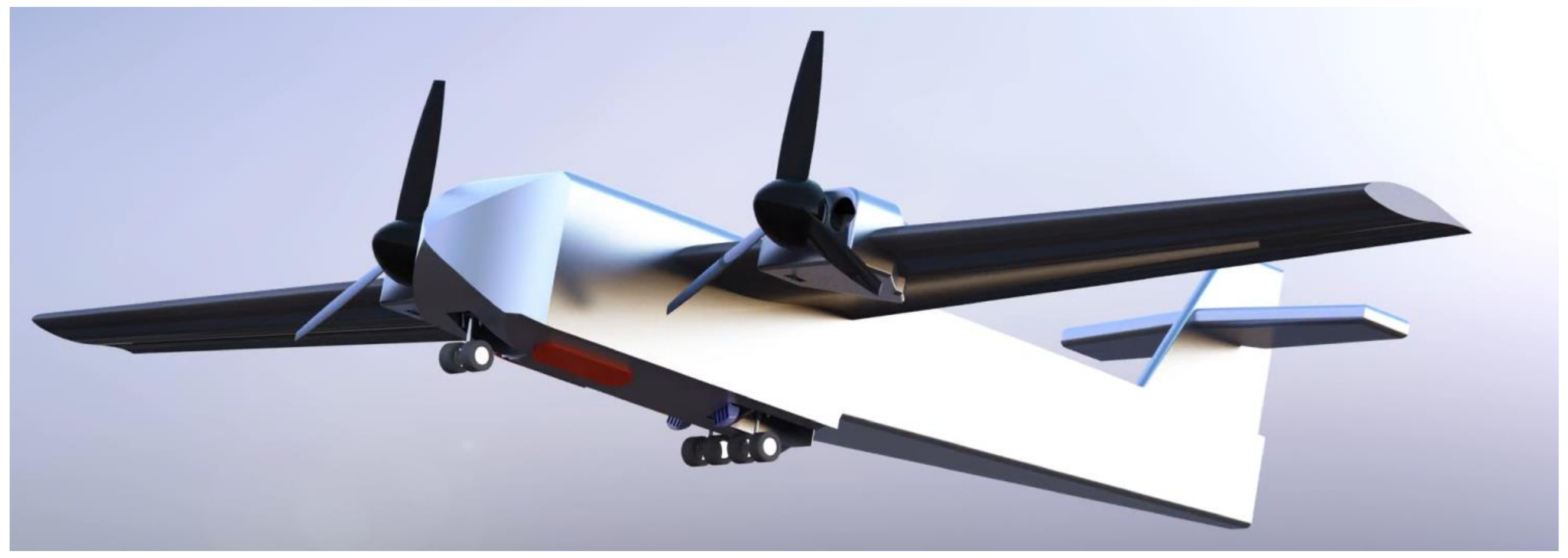

Figure 8: Final CAD Model

Fire Simulation and Strategy Optimization

MATLAB was used to calculate and visualize our drone strategy in action.

To begin, data on lakes, air tanker bases, and BC geography was found.

Then, a sample of 5000 random fire start locations was created, and the distances to the nearest lake and airtanker base was summarized in histograms (Figure 5).

Next, calculations for water line creation time was performed using genetic algorithm parameters. Figure 6 shows the average time required to create a 10 km water line for various fleet sizes and fire to lake distances.

To explore the indirect attack strategy, Dr. Hinman's fire simulation (Figure 7) assessed the progression of the fire over different periods of time. Knowing this, an optimal strategy for containing the fire can be developed using an appropriate fire line pattern, length, and distance from the fire.

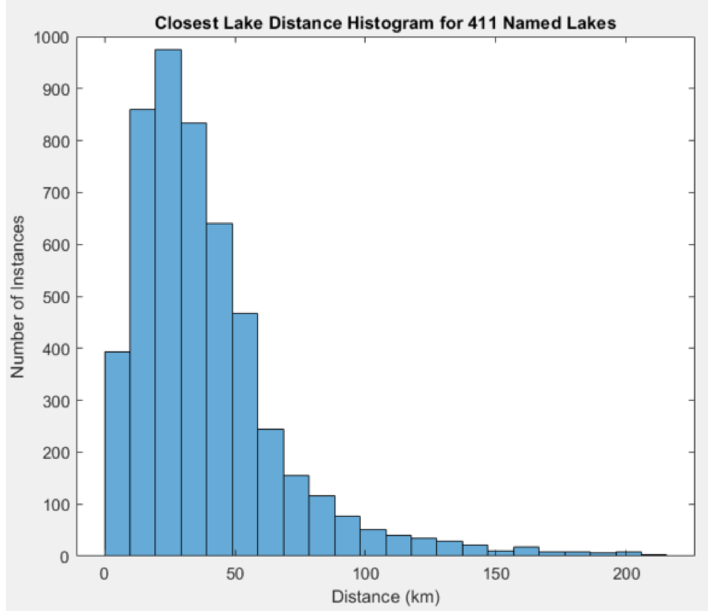

Figure 5: Fire to Lake Distance Histogram

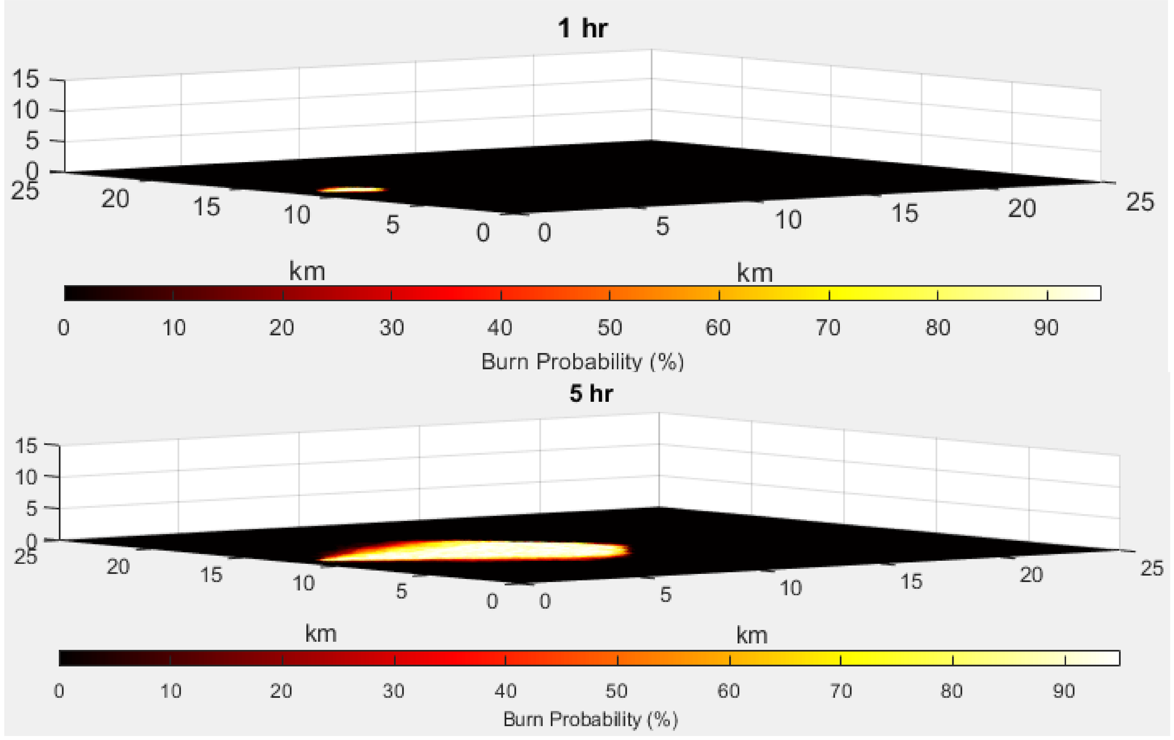

Figure 7: Progression of Fire Spread over Time for 1hr and 5 hrs [5]

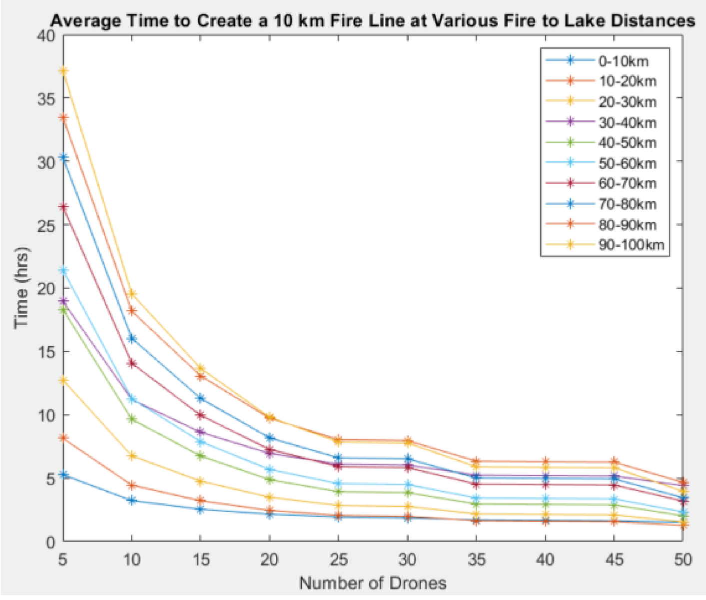

Figure 6: Average Time to Create 10 km Water Line at Given Distances and Fleet Sizes

Optimized Drone and Flight Parameters

Ultimately, the final deliverable of the project was to conceptualize a design for a drone fleet to fight wildfires. Taking all of the work in the previous sections together, Tables 2 and 3 show the optimized drone and flight parameters that we have determined.

Table 2: Optimized Drone Parameters

Final Drone Parameters	
Wingspan	19.8 m
Payload	866.2 L
Fuel Mass	100.3 kg
Total Mass	1723 kg
Power Required	444.5 kW
Flowrate (per drone)	2.045 L/s
Scoop Area	6.8×10^{-3} m^2

Table 3: Optimized Flight Parameters

Final Flight Parameters	
Fleet Size	20 Drones
Range	515.8 km
Cruise Velocity	103.3 km/hr
Skimming Velocity	86.7 km/hr
Max Response Time	2.65 hr
Minimum Lake Size	22561 m^2
Skim Distance	127.1 m

Conclusion and Future Goals

All in all, the feasibility of drone fleet based firefighting strategies have been extensively evaluated throughout the duration of our project. Even though our analysis was at the conceptual level, it can be said that drones have the potential to be an effective solution over existing solutions and can improve safety for ground crews, decrease response times (thus minimizing fire damage and spread), and utilize geographic features (such as small lakes) that are not being utilized currently.

Looking forward to the future, it is important to note that this capstone project has been the continuation of a previous capstone project from 2020-2021. Although there has been considerable progress made by all students involved, there are many opportunities and areas for further investigation. For example, the use of simulations to model wildfire progression takes into accounts hundreds of variables that were not considered in our analysis. In addition, more detailed engineering design can be performed on specific parts of the drone, such as the fuselage, wing, tail, etc. – entire capstone projects can be dedicated to each one of these aspects. The application of drones in firefighting is such a novel field and the untapped potential is limitless.

References
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