Portable UAV Design for Wildfire Safety Efforts

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Introduction

Wildfires are a natural phenomenon that have become an increasingly concerning public safety challenge that are predicted to continue to get worse as the climate changes. Traditional firefighting techniques are effective but pose significant safety challenges to firefighters and are limited by the capability of current technology. Fire departments across the United States have begun to integrate unmanned aircraft into their firefighting technologies to gather information and decrease the workload of firefighters operating under these stressful and dangerous conditions [1][2]. This research focusses on the selection of UAV firefighter support missions and the corresponding vehicle design.

Methods

In the initial phase of this project, research was conducted to determine payload capabilities of existing drones as well as to determine what firefighting missions are presently being serviced by UAVs. Additionally, we contacted Bradley Koeckeritz who serves as division chief for the UAS program at the Department of Interior and worked previously as an aerial firefighter. He provided crucial feedback on our proposed missions and described several challenges with manned aerial firefighting and monitoring procedures that could be mitigated with UAS. Additionally, he discussed some technological challenges that he experiences with his UAVs.

In the Second Phase of the project, vehicle design requirements were determined, and the vehicle design phase began. Preliminary CAD models were developed and modified momentum theory (MMT) equations [3] were used to compare different design attributes. Once basic vehicle designs were chosen the CAD models were refined and mission simulations were developed in MATLAB based on MMT methods for determining rotorcraft performance in hover, cruise and climbing flight.

Mission Selection & Vehicle Requirements

One of the purposes of UAVs in firefighting is primarily to help firefighters do their job safely and effectively and to provide support at times or in areas which are inaccessible by manned aircraft or personnel. The other purpose is to automate jobs that may be safe and effective but can be done in a more resource efficient way with unmanned aerial technologies. We identified four broad areas of wildfire fighting where UAVs can be of benefit: data collection & fire monitoring, logistics, fire suppression, and fire prevention. This poster will focus primarily on the logistics as well as data collection & fire monitoring areas.

Although many drones are already in use for data collection & fire monitoring [1], they cannot fly for very long and their range is very limited. This is a challenge for monitoring missions which require surveying large areas or surveying a region over a long period of time. These missions have traditionally been done by manned vehicles, however low visibility conditions make these missions to dangerous to fly. Furthermore, nighttime flights are rare due to increased risk to the pilots. Therefore, we identified range, endurance, and low visibility operation as the primary design drivers for fire detection, monitoring, and search and rescue (SAR) missions.

Logistics missions pose the most obvious technological challenge for small UAVs since they sometimes involve carrying large payloads. A small portable UAV that could carry large payloads, however, would be able to conduct crucial logistics missions in poor conditions and as autonomy advances some of these missions may even be able to be pre-programmed cutting environmental and financial costs associated with manned gas-powered helicopters. Therefore, we identified payload capacity and low visibility flight as the primary design driver for the logistics mission.

Since range can be increased by replacing a payload with batteries, a single vehicle was designed whose payload can be switched out for a large battery boosting the range over 100 miles. The vehicle also can be made slightly shorter decreasing the frontal flat plate area and therefore the parasite drag in cruise which can provide a slight additional benefit in cruise. Due to limited space on this poster and generally similar general specifications, the vehicle with this modification made to its frame will not be discussed further however it is good to keep in mind that the maximum range reported can actually be increased even further beyond the 183 km maximum range discussed in the design attributes section.

The fire suppression and prevention missions have more balanced requirements. They do not necessarily need extremely long range, or extremely large payload, however these missions require carrying and delivering a suppression or preventative chemical or burnout inducing payload to the desired site. The focus on these missions was largely on the delivery mechanism, the sensors, portability and reliability.

Modified Momentum Theory Model

The modified momentum theory model used for the vehicle performance prediction is based on the chapter on momentum Theory in Leishman's Helicopter Aerodynamics textbook [3]. The primary equations used are:

$$P_{hover} = \frac{T^{3/2}}{\sqrt{2\rho A}} \quad (1)$$

$$P_{vert\_climb} = \frac{T^{3/2}}{\sqrt{2\rho A}}\left(V_{cl}\sqrt{\frac{\rho A}{2T}} + \sqrt{\frac{\rho A {V_{cl}}^2}{T} + 1}\right) \quad (2)$$

$$P_{cruise\_climb} = T\left(V_{inf}\sin\alpha + v_i\right) \quad (3)$$

$$v_i = \frac{T}{2\rho A\sqrt{(V_{inf}\cos\alpha)^2 + (V_{inf}\sin\alpha + v_i)^2}} \quad (4)$$

$$V_{inf} = \sqrt{{V_{cr}}^2 + {V_{cl}}^2} \quad (5)$$

$$\alpha = \tan^{-1}\frac{D}{L} + \tan^{-1}\frac{V_{cl}}{V_{cr}} \quad (6)$$

The fuselage drag was estimated based on the drag coefficient calculated from the UH-60's equivalent area drag coefficient [4] and its measured frontal area. The estimation was confirmed by comparison to similar shapes at a similar Reynold's number (1e6) [5].

CAD model & Vehicle Highlights

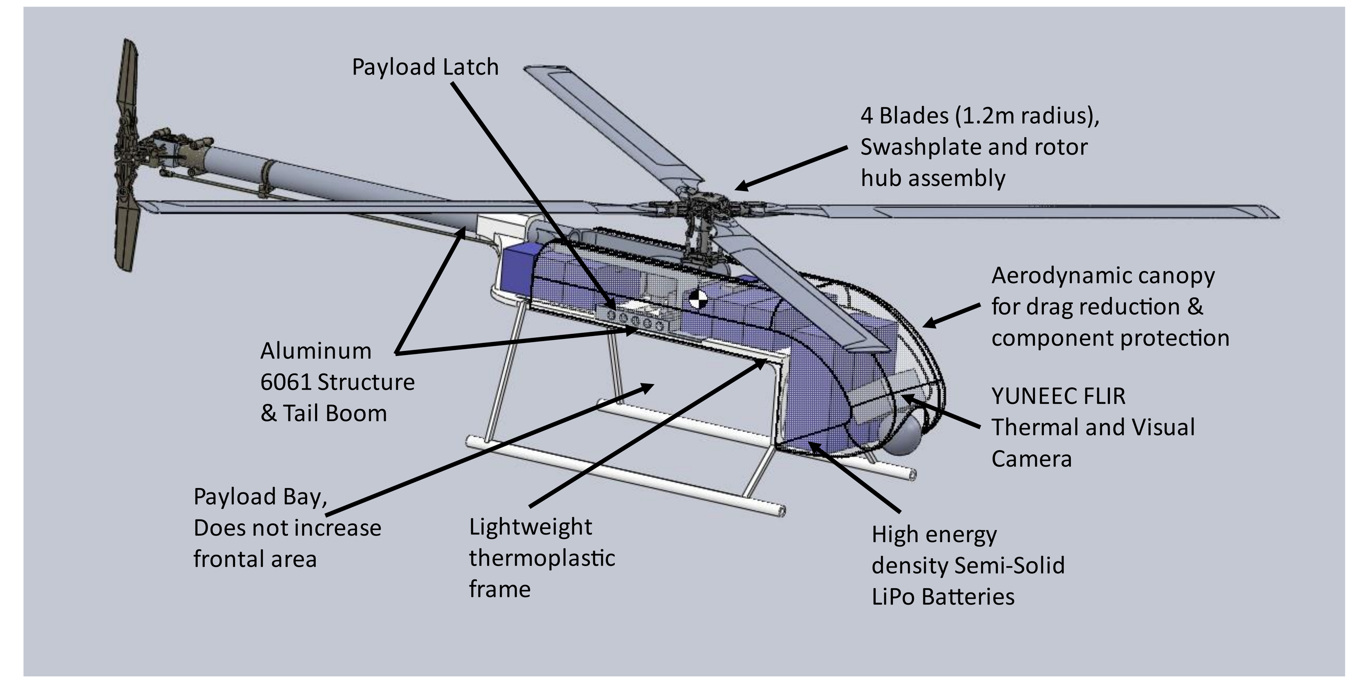

Figure 1: CAD Model of vehicle showing vehicle highlights

Design Attributes

Max. GTOW	Motor Power	Empty Weight	Max Payload	Max. Altitude	Range @Vbr (max Payload)	Range @Vbr (no Payload)
55 kg	10 kW	11.63 kg	23 kg	7000 m (23000 ft)	91 km @ 90 km/h	150 km @68.4 km/h
Max Hover Endurance (max payload)	Max Hover Endurance (no Payload)	Endurance @ max. Power	Max. Climb Rate (20 kg Payload)	Vbcl (20 kg Payload)	Max Vert. Climb Height @ Vbcl	Climbing Range @ Vbcl
29 min	62 min	26.6 minutes	4.0 m/s (785 ft/min)	18.0 m/s (64.8 km/h)	6.39 km	28.8 km

Table 1: Selected Vehicle Specifications

As shown in the chart above, the base mission for the monitoring and logistics (payload) missions can deliver heavy payloads significant distances. The range can also be increased to 183 km or 114 miles without a payload by replacing the payload with a 20 kg battery. This vehicle also has excellent climb performance with the ability to achieve a solid rate of climb for almost half an hour. In practice this means the vehicle can easily clear even the tallest mountains and still have significant range to deliver payloads in mountainous terrain in difficult conditions.

Performance Graphs

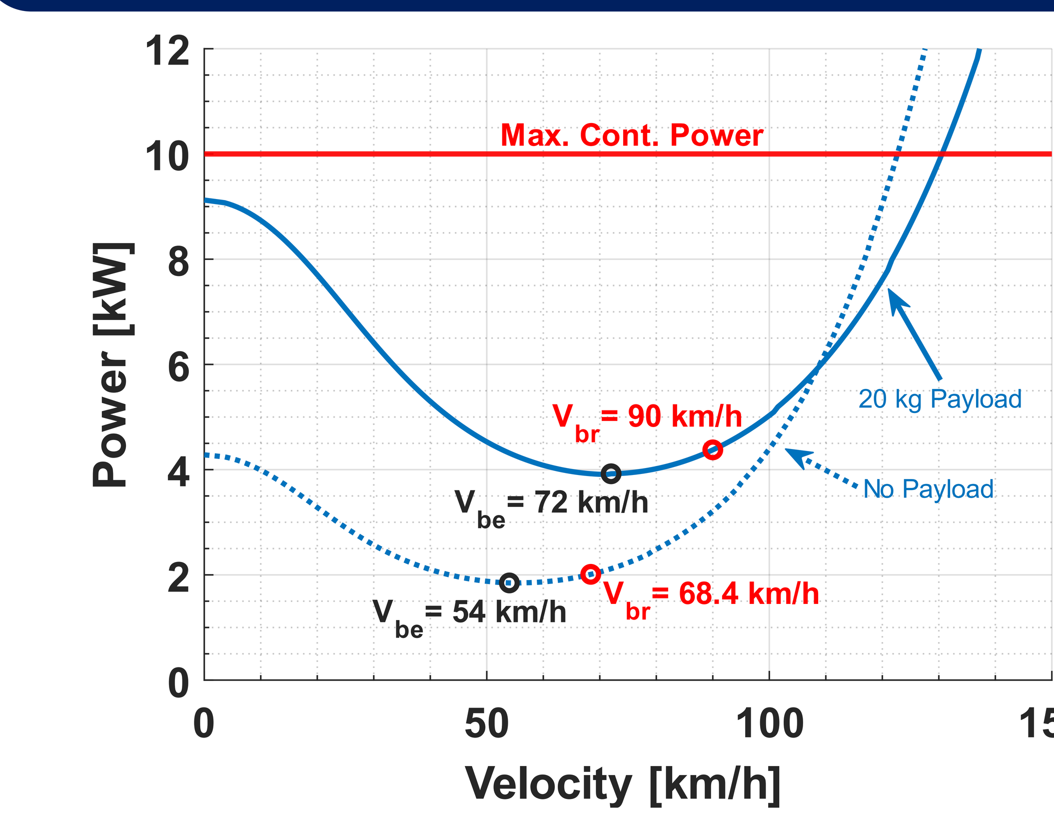

Figure 2: Vehicle Power Curve with and without the Payload

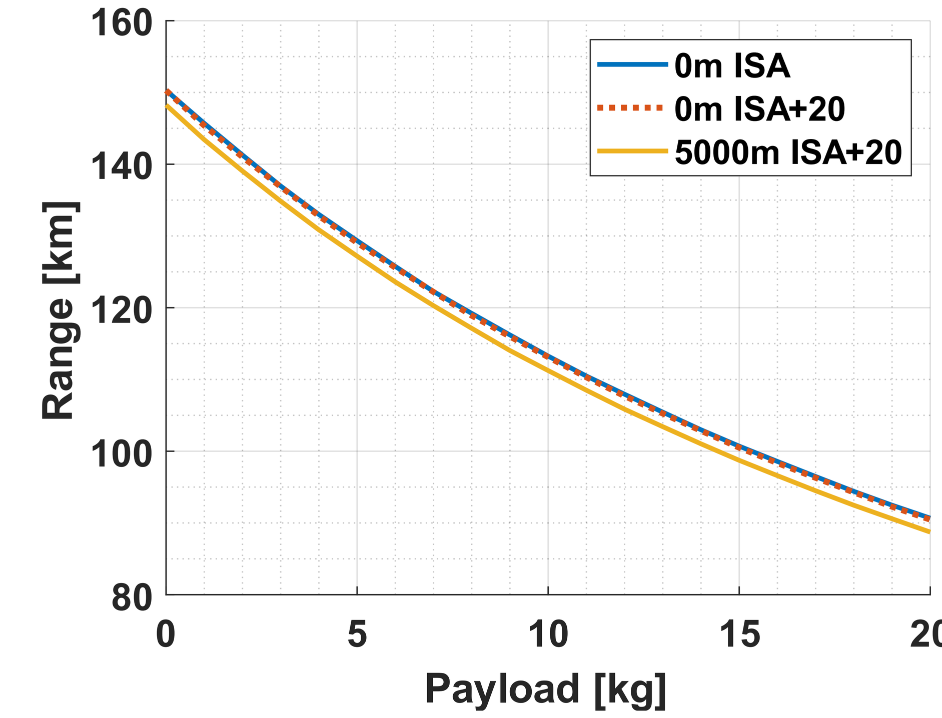

Figure 3: Range vs. Payload of Vehicle

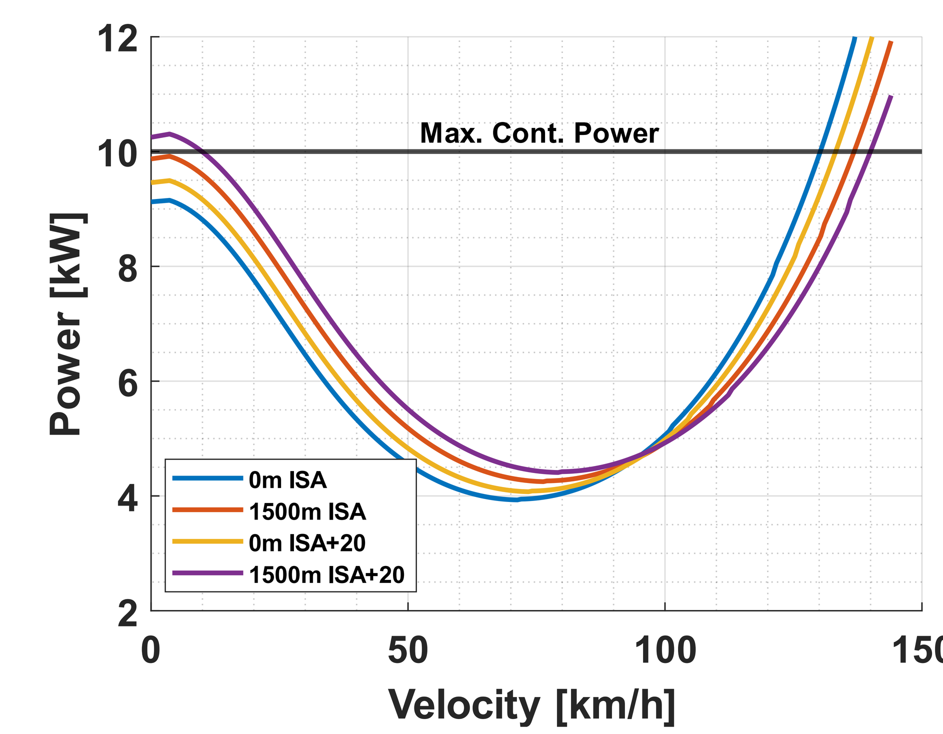

Figure 4: Vehicle Power Curve at different atmospheric conditions. As Temperature and Altitude increase, power increases at low speed and decreases at high speed

Summary

This project details the design of unmanned rotorcraft for wildfire fighting operations. The two vehicles focused on in this study are single main rotor vehicles based on a single frame. These vehicles were designed for high payload and long endurance missions and for long range flight and sensing in poor conditions. Hexacopters were also designed for fire suppression and prevention missions however those vehicles are not the focus of this presentation.

Acknowledgements

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References

[1] Moro, Teviah. *"Drones Latest Hamilton Fire Department Recruits."* Thespec.com, 3 July 2021.
[2] Kalischer-Coggins, Aaron. *"How Drones Are Fighting Fire with Fire in the American West."* TheHill, 26 July 2021.
[3] J Gordon Leishman. *Principles of Helicopter Aerodynamics*. Cambridge, United Kingdom, Cambridge University Press, 2017.
[4] Yeo, Hyeonsoo & Bousman, William & Johnson, Wayne. (2004). Performance Analysis of a Utility Helicopter with Standard and Advanced Rotors. Journal of the American Helicopter Society. 49. 250-270. 10.4050/JAHS.49.250.
[5] "Shape Effects on Drag." *NASA*, NASA, www.grc.nasa.gov/www/k-12/airplane/shaped.html.