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FIREFLY: A UAV SOLUTION FOR WILDFIRE SUPPORT AND MITIGATION

REVISED AND EDITED FOR NYU GLASS PAPER

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ABSTRACT

Wildfires are a growing global concern, posing significant threats to ecosystems, property, public safety and there are economical ramifications. To address the urgent need for early detection and active fires, our team is developing a UAV (named FireFly) optimized for wildfire surveillance with a primary focus on endurance flights that are meant to scan regions of land and collect weather information to help determine wildfire circumstances. The goal is to create an aerodynamic, fuel-efficient platform capable of long-endurance flights over vast, fire-prone areas and relay effective real time data to firefighting agencies.

The UAV's airframe is engineered to minimize drag and maximize lift-to-drag ratio, ensuring fuel efficiency and extended operational range. The fuselage and wing structures are designed using lightweight materials to reduce overall weight without compromising structural integrity. Computational Fluid Dynamics (CFD) simulations and testing to justify the UAVs airfoil choice, enabling optimal aero-performance in different environmental conditions.

This initiative aligns and was inspired by the United Nations Sustainable Development Goals , particularly Goal 13: Climate Action but by the nature of the project it is also applicable to Goal 9: Infrastructure and Goal 11: Sustainable Cities. With the goal of contributing an innovative solution that would combat wildfires to protect ecosystems, public safety, property, and protect the economic stability of regions that would be affected.

NOMENCLATURE

AI - Artificial Intelligence
CFD - Computational Fluid Dynamics
FAA - Federal Aviation Administration
GPS - Global Positioning System
IR - Infrared
IP - Ingress Protection (e.g., IP65 or IP67 for water/dust resistance)
RF - Radio Frequency
UAV - Unmanned Aerial Vehicle
UN - United Nations
UN SDG - United Nations Sustainable Development Goals

1. INTRODUCTION

1.1 PROBLEM AND DEFINITION

MOTIVATION AND BACKGROUND

Forest fires are an escalating global concern, exacerbated by the adverse effects of climate change and forest preservation. These fires devastate ecosystems, displace communities, and lead to significant economic losses. The majority of forest fires, however, are preventable if detected and addressed early. Fires often begin as small, localized patches, spreading rapidly due to favorable conditions such as strong winds, dry vegetation, and high temperatures. Timely intervention during these early stages can significantly reduce the scale and severity of such disasters.

The impacts of forest fires extend beyond environmental degradation. Communities in high-risk areas face displacement, financial hardships, and social disruption. Many insurance providers hesitate to cover properties in fire-prone regions, causing substantial declines in property values and further destabilizing local economies. This situation highlights the urgent need for innovative and cost-effective solutions to mitigate the risks and damages associated with forest fires.

In addition to this, during my internship with Lockheed Martin there was a company-wide intern competition where the prompt of the competition was to design something that would help firefighters help fight wildfires. I came up with the idea of a fixed-wing aircraft that would perform surveillance and collect weather data and relay the information back to the control center and communicate this information to first-responders and firefighters. This was one of the ideas within my team and was a very unpopular one and had to beg and offer a lot of my time and resources to work on my idea which ended up paying dividends as the idea for FireFly was born and won the entire competition and secured a 1st place victory. Since then , I have now decided to pursue this idea although with slight modifications as my original idea is now proprietary information of Lockheed Martin and no longer mine.

SIGNIFICANCE AND UNIQUENESS

Our project aims to use small fixed-wing unmanned aerial vehicle (UAV) technology to address the growing challenge of forest fire management efficiently and innovatively. The proposed UAV is designed for simplicity and ease of operation, requiring minimal training for deployment. Its compact size compared to traditional UAVs makes it highly portable, facilitating effortless launch and landing even in challenging terrains. Fixed-wing UAVs, in particular, offer a transformative solution by enabling continuous, cost-effective surveillance of remote and high-risk areas. Unlike helicopters, which are commonly used for fire surveillance, UAVs provide superior advantages in terms of range, affordability, and accessibility. Helicopters, while effective, are costly to operate for extended periods and face challenges in reaching remote regions. The proposed UAV solution distinguishes itself with its scalability, affordability, and seamless deployment capabilities. Engineered for 24/7 operation, it ensures early fire detection and supports proactive responses from fire departments, potentially saving lives, preserving ecosystems, and protecting infrastructure. This project embodies a forward-looking application of UAV technology, addressing a critical global challenge with innovation and efficiency. Moreover, it directly supports the United Nations Sustainable Development Goal 13: Climate Action, by enhancing wildfire preparedness and resilience. As climate change increases the frequency and intensity of wildfires worldwide, the deployment of accessible, efficient technologies like UAVs becomes crucial in mitigating environmental damage and protecting vulnerable communities. By improving early detection and real-time response, our project contributes to international efforts aimed at adapting to climate-related hazards and reducing their long-term impact.

Proposed Technologies and Methodologies

Key design elements include an integrated communication system that facilitates collaboration with nearby UAVs in a larger network. This capability ensures efficient area coverage, seamless data exchange, and enhanced detection accuracy. The UAVs compact size further contributes to its ease of deployment and operational flexibility, especially in remote or inaccessible areas. Equipped with advanced sensors, the UAV will detect potential fire hazards, such as heat signatures or smoke plumes, enabling comprehensive and precise surveillance of forested regions. This modular and scalable design positions the UAV as a cutting-edge tool in modern forest fire prevention strategies, offering both innovation and practicality in addressing a critical global issue.

1.2 PRIOR ART

NASA's Ikhana UAV has been employed as an advanced tool for wildfire detection and management. It uses thermal-infrared imaging sensors to detect heat signatures from fires. By overlaying this data onto maps, it provides real-time information to firefighting agencies, enabling better decision-making. This UAV addresses the problem of detecting fires in remote and hazardous locations where traditional methods struggle.

Ikhana is equipped with thermal-infrared imaging sensors capable of detecting heat through thick smoke and haze. It also includes real-time data transmission capabilities, enabling the relay of critical information to agencies like the Interagency Fire Center. These technologies allow Ikhana to map fire progression accurately and monitor hotspots over large areas.

Ikhana has demonstrated the ability to conduct long-endurance missions, covering multiple fires in a single flight. By providing near-real-time data, it has enhanced firefighting efforts and resource allocation efficiency. Its technology has improved situational awareness, allowing incident commanders to make informed decisions quickly, which is crucial for mitigating the spread of fires.

While Ikhana has been highly effective, traditional approaches such as manned aircraft or ground-based surveillance have limitations. These include high operational costs, limited range, and the inability to provide real-time data in inaccessible areas. Although Ikhana addresses many of these issues, reliance on UAVs still requires significant investment in technology and trained operators.

Fire-Hawk is a derivation of LockHeed Martin’s exclusive line of BlackHawk U60s , which is the current method of fire surveillance and assistance. The helicopter is manned and presents active challenges. The biggest challenge is operations done during the night , in which it gets very dangerous for pilots especially in the wildfire environment.

2. REQUIREMENT

Customer Needs

In an interview we conducted with LA County Fire Captain *Eric Tucker*, we gained valuable insights into the design requirements necessary to make our UAV competitive with existing alternatives. Captain Tucker emphasized that our UAV would not replace planes and helicopters, as those are primarily used for firefighting rather than surveillance. Additionally, he noted that it would be challenging to operate the UAV during the day when an active fire is ongoing, as airspace is reserved for firefighting aircraft. However, he highlighted key applications for our UAV, including surveillance of high-risk areas and nighttime fire mapping.

Current methods for mapping fires, such as walking the perimeter or using rotary drones, have significant limitations. Walking the perimeter is time-consuming and hazardous, while rotary drones struggle with high winds and have limited flight durations. Captain Tucker stressed that the Santa Ana winds, which rapidly spread fires, make combating forest fires particularly challenging. Therefore, he underscored the importance of designing a UAV capable of flying effectively in windy conditions, making it a critical asset in fire management efforts.

Functional Requirements

Range: The rover's range requirement depends on the specific areas the UAV will operate in. For example, California's forests cover approximately 40,000 square miles. Taking the square root of this area, we get a side length of approximately 200 miles. But since we are building a smaller UAV that is going to work with other UAV to collect datas. We are aiming for a range of 100 miles.

Altitude: Forest trees can reach heights of up to 200 feet. To effectively survey a large area in a single trip, the UAV must maintain an altitude of at least 1,000 feet. Additionally, the required altitude will depend on the capabilities of the onboard sensors.

Design constraints

Prospective Performance metrics

Deployment speed: Quick setup and launch capability in under 10 minutes to respond rapidly to emergencies.

Flight Range and Endurance: Must achieve long-range flight (e.g., 50–100 km) to cover large forested areas. Endurance of at least 5-8 hours to conduct extended surveillance missions without recharging or refueling.

Wind resistance: Ability to operate in strong winds (e.g., Santa Ana winds reaching 40–60 mph). Stability and control in turbulent air conditions.

Payload Capacity: Must carry essential equipment, including thermal and optical sensors, cameras, and communication modules. Lightweight structure to ensure energy efficiency without compromising payload.

Operational Altitude: Capable of flying at altitudes suitable for fire detection and mapping (e.g., 200–1,000 meters).

Relevant Codes and Regulations

FAA Regulations (U.S)

- Must comply with Federal Aviation Administration (FAA) regulations for UAV operations, such as Part 107 (Small Unmanned Aircraft Systems).
- Altitude limits: 400 feet above ground level unless specific waivers are granted.

Environmental and Safety Standards

- Must withstand high temperatures near fires without compromising performance (heat resistance up to 120°C or more).
- Meet IP standards for water and dust resistance (e.g., IP65 or IP67).

Battery and Energy Standards

- Use lithium-ion or other batteries compliant with UN 38.3 for safe transportation.
- Fuel Source Determination

- Adhere to energy efficiency and recycling standards (e.g., IEC 62619 for secondary lithium batteries).

Night Operations

- If designed for nighttime use, comply with lighting standards such as visible and anti-collision lighting as per FAA rules.

Design Data

Table 1 : Table of Values

Parameters	Units (Metric)
Takeoff Weight	10
Payload Weight	5
Crew Weight	0
Fuel Weight	0.71
Empty Weight	4.29
Specific Fuel Consumption	2.250324159
Velocity	20
Aircraft length	1.6
Wing span	2.8
Aspect Ratio	13.7254902
Wing Area	0.5712
Tip Chord	0.154
Root Chord	0.254
Lift - Drag_max Ratio	29.9102478

The aerodynamic performance evaluation highlights the aircraft design's desired efficiency, as evidenced by its calculated lift-to-drag ratio. This metric reflects the design's ability to generate significant lift while minimizing aerodynamic drag, emphasizing its streamlined structure and optimized performance.

Such a high ratio demonstrates that the aircraft is well-suited for operations requiring energy efficiency and stable flight characteristics. This analysis not only confirms the effectiveness of the design but also underscores its alignment with the intended operational goals, showcasing a well-balanced integration of aerodynamic principles and functional capabilities.

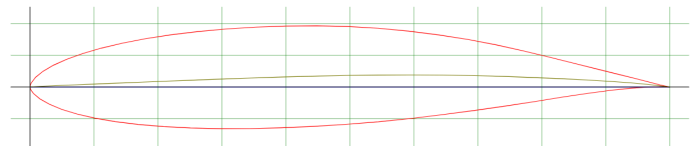

Figure 1 : Airfoil Cross-Section

Figure 2 : Airfoil Cross-Section Manufactured

The LS(1)-0417 airfoil is an excellent choice for aerodynamic applications due to its high efficiency and versatile performance.

With a thickness-to-chord ratio of 17%, it strikes a balance between low drag and structural integrity. Its ability to maintain laminar flow over a significant portion of the chord reduces skin friction, improving overall efficiency.

The airfoil performs well at moderate Reynolds numbers typically around 10^5 to 10^6, making it suitable for UAVs and light aircraft.

Additionally, its smooth stall characteristics and high lift-to-drag ratio ensure stable and predictable performance, making it a reliable option for designs requiring endurance and operational efficiency.

3 CONCEPT DEVELOPMENT

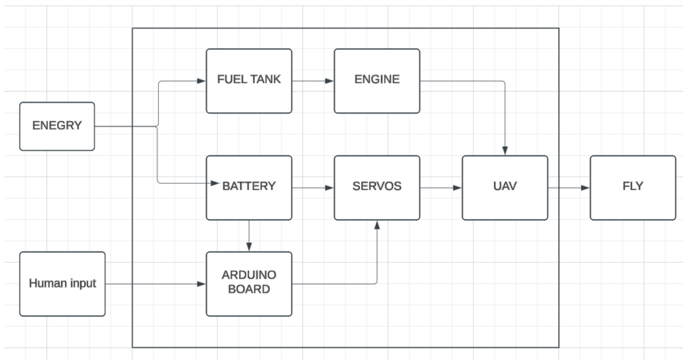

FIGURE 3: FUNCTIONAL DIAGRAM

The functional diagram outlines the core components and workflow of the wildfire detection UAV system, named **Firefly Systems**. The system integrates energy storage, sensory data processing, and UAV compatibility to ensure efficient wildfire detection and reporting. The sensory system collects and analyzes heat readings to identify potential fire risks, leveraging durable and reliable sensors capable of operating in harsh environments such as smoke and high temperatures. These sensors feature a 180-degree field of view and a detection range of up to 100 meters. The system transmits critical data through a transmitter, ensuring timely communication of fire risk information. Designed for seamless integration into UAVs, the system is compact and optimized for effective aerial operations.

Engine Model	Price	Weight	Size
DLE-60 Twin Gas Engine	$799.99	4.1 lbs	10.4 x 5.7 x 5.7 in
OS Engines GF40 4-Stroke Gas Engine	$699.99	2.7 lbs	6.6 x 3.5 x 4.9 in
Roto 35 FS Four-Stroke Gasoline Engine	$950.00	4.85 lbs	7.5 x 4.3 x 5.5 in
Saito FG-30B 4-Stroke Gas Engine	$899.99	2.9 lbs	6.1 x 3.9 x 5.5 in

Table 2: SCORING MATRIX PART ONE

3.1 Preliminary Design

Design Alternatives

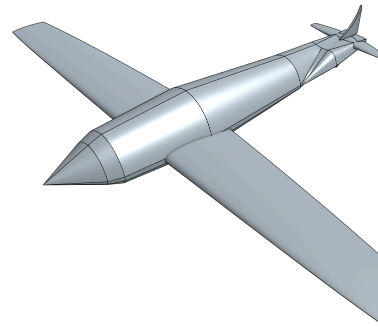

FIGURE 4: FIRST PRELIMINARY DESIGN OF UAV AIRFRAME

This CAD model was initially designed as a conceptual airframe with an emphasis on aerodynamic efficiency and minimal drag. The slender and streamlined shape was intended to optimize lift-to-drag ratios, allowing for extended flight durations and improved fuel efficiency. However, upon further evaluation, it became evident that the sharply tapered nose and seamless transitions between components would pose significant manufacturing challenges. These sharp geometries would complicate production using traditional methods such as composite molding or sheet metal forming. Additionally, the lack of defined attachment mechanisms for the wings and tail raises concerns about structural integrity during assembly and flight.

Several key issues were identified in this design. The thin tail section lacks visible reinforcement, potentially leading to structural failure under operational loads. The design also does not account for essential features, such as openings for electronic components, payload storage, or ventilation. Without a defined camera or sensor mount, the airframe fails to meet its intended purpose of wildfire detection. Furthermore, the abrupt transition between the fuselage and wings could induce turbulence, reducing aerodynamic efficiency. These shortcomings highlight the need for a redesign that focuses on manufacturability, structural integrity, and functional integration to meet operational goals.

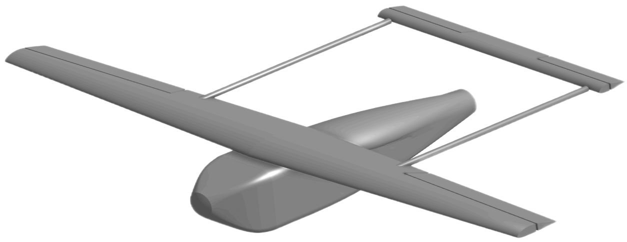

FIGURE 3: PRELIMINARY DESIGN OF UAV AIRFRAME

The front part was designed to allow the trajectory of the aircraft to be as smooth as possible. This is because of the purpose of our aircraft to glide along the forest areas. The new design allows for a more stabilized control of the aircrafts yaw motion which is important as fires can propagate quickly. Additionally, in this new design the propulsion system was geared to a piston propeller mechanism because it simplified the scope of our design. The engine that is going to be used The fuselage should feature a more gradual taper at the nose and tail sections, using curved surfaces instead of sharp edges to reduce manufacturing complexity and improve aerodynamic flow. A modular design with clear attachment points for the wings and tail would enhance structural integrity and simplify assembly. Additionally, incorporating a flatter underbelly would allow easier integration of payload compartments, electronic housing, and sensor mounts. For the purpose of the aircrafts service For wildfire detection, the airframe could include a dedicated section with reinforced cutouts for sensors, such as infrared and optical cameras, to operate effectively. Designing these cutouts to minimize drag while providing unobstructed views for the sensors would improve the UAVs functionality. Wing geometry could benefit from a high aspect ratio with blended wing roots to reduce drag and improve lift, enhancing flight efficiency. Materials such as lightweight carbon fiber composites would maintain durability while ensuring the aircraft remains fuel-efficient. This revised design would address the shortcomings of the initial concept, allowing for effective wildfire surveillance while being practical to manufacture and assemble.

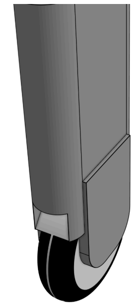

FIGURE 4: PRELIMINARY DESIGN OF FRONT LANDING GEAR

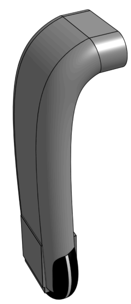

FIGURE 5: PRELIMINARY DESIGN OF BACK LANDING GEAR

The design of the landing gear is a tricycle landing gear setup, with two main wheels located near the center of gravity and a steerable front nose wheel, ideal for UAVs. This configuration provides stability during takeoff and landing and is easier to control on the ground compared to taildragger configurations. Essentially, the nose wheel would be used for steering during taxiing, offering greater maneuverability. In addition, the landing gear will be made from lightweight yet strong materials such as aluminum alloys. This ensures the UAV remains light for better endurance and flight efficiency.
The material should be corrosion-resistant to endure various environmental conditions such as contact with water and high temperatures which typically cause corrosion.

Table 3: Bill of Materials

Parts	Quantity	Price
Engine	1	$310
Propeller	1	$10
Gas tank	1	$10
Wheels	3	$10
PVC Pipe	2	$26
Steel Wire roll	1	$8
Servos	4	$10
Arduino Board	1	$30
Servo Rods	10	$10
Battery	1	$20
Insulation Foam Board	10	$22
Total		$466

Table 4: Comparison Table

Sub-Function	Option 1	Option 2	Option 3
Propulsion	Electric Motor	Gas Motor	Turbine
Frame material	Wood	Aluminum	Foam
Propeller type	Tractor	Pusher	Double Prop
Landing Gear	Tail dragger	Tandom	Tricycle-type
Landing Gear	Fixed	Fixed	
Airfoil	NACA 23015 1935	NACA LS(1)-0417	M-6 1926
Wing shape	Rectangular	Swept	Tapered

We went with the gas motor because of the larger energy density compared to an electric motor with a battery. We needed the larger energy density because we wanted the increased range. We chose wook for the frame material because it is lighter than aluminum but has more structural support than foam. We went with the pusser motor because the propeller will be protected in the event of an emergency landing. We went with the tricycle- type landing gear because of the stability it provides. We decided on a fixed landing gear to save on weight. We went with the rectangular wing design because it will be easier to make.

4 CONCLUSION AND FUTURE WORK

The FireFly UAV represents an innovative and practical solution to the escalating global threat of wildfires. By integrating aerodynamic efficiency, modular design, and real-time sensing technology, the platform demonstrates the potential for transformative change in wildfire surveillance and management. Its compact structure, long-range capability, and affordability make it a strong candidate for widespread deployment in fire-prone regions, particularly those underserved by current infrastructure.

This project directly supports the United Nations Sustainable Development Goals, particularly Goal 13: Climate Action, by providing a scalable technological response to climate-induced natural disasters. It also contributes to Goal 9: Industry, Innovation, and Infrastructure and Goal 11: Sustainable Cities and Communities, by enhancing disaster resilience and supporting sustainable development in vulnerable ecosystems.

Looking ahead, future work will focus on experimental validation and system integration. The team plans to begin full-scale construction of the aircraft body, targeting completion by the end of April. A test flight is scheduled before May, allowing time for system-level refinements. Simultaneously, collaboration with the systems team will ensure seamless assimilation of sensor arrays and data transmission tools. Through these next phases, FireFly aims to evolve into a fully functional, field-ready UAV capable of aiding first responders and protecting communities on the front lines of climate change.

ACKNOWLEDGEMENT

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I also extend our heartfelt thanks to Firefly Systems for their generous assistance in providing research resources and knowledge about various aircraft technologies, which greatly enriched our understanding and development process.

Lastly, I am profoundly grateful to all members of the Firefly Airframe team. Your hard work, dedication, and collaborative spirit throughout the semester have been the cornerstone of this project's progress and achievements.

My biggest thanks to the GLASS team for pushing me to become the best version of myself I could be and a more specific thank you to Kat Arredondo her support is invaluable and would take a lifetime to give back to return the favor.

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APPENDICES

1. *DataFly.xlsx*