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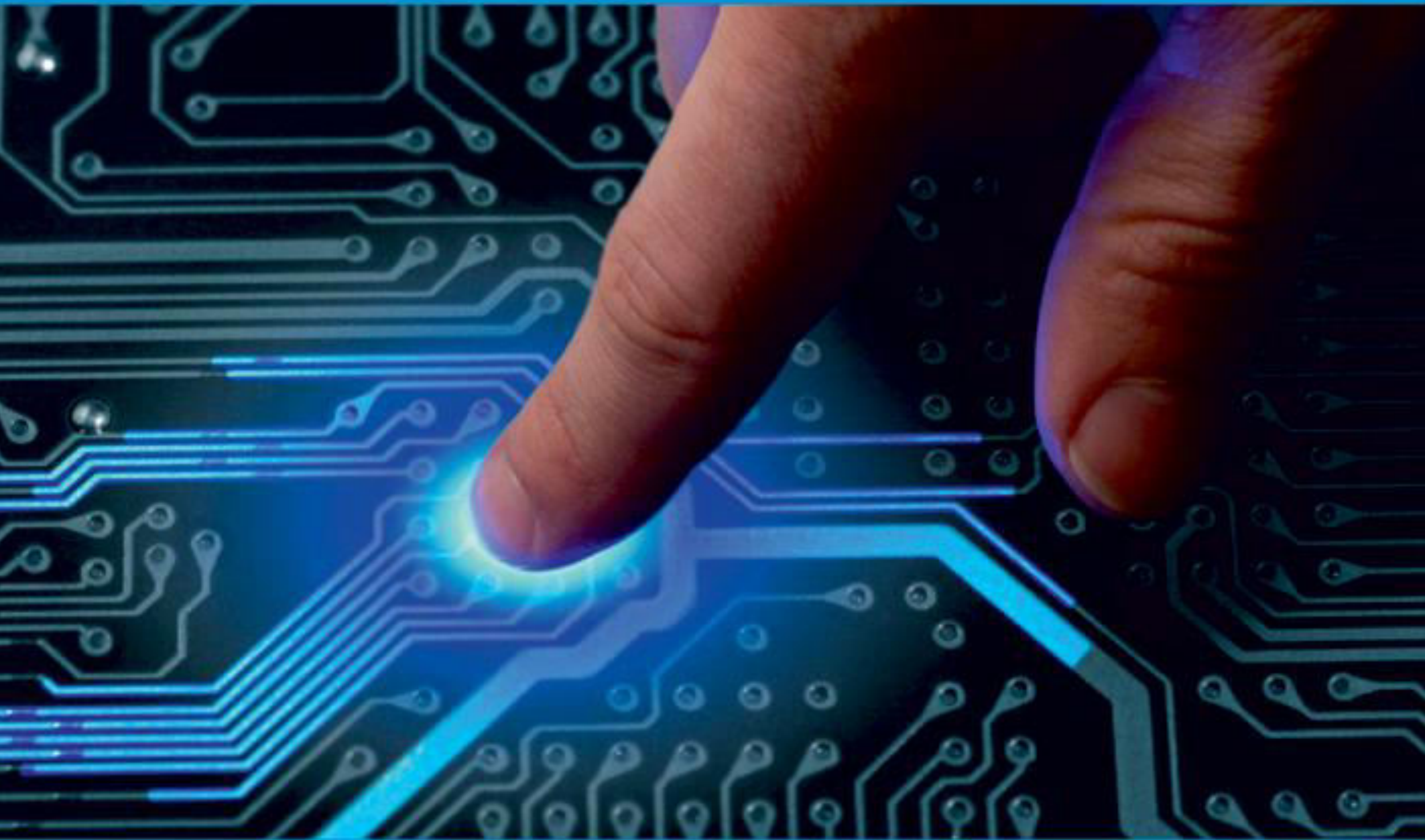

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# Spy Bird for Military Purposes

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**ABSTRACT**: This research paper focuses on the development and evaluation of the Spy Bird, an ornithopter-based aerial surveillance platform. The paper highlights the advantages of ornithopters over conventional aircraft, emphasizing their varied flight characteristics and potential for VTOL maneuvers. The Spy Bird is designed to provide real-time surveillance video of terrorist camps through an FPV camera, enhancing situational awareness for military operations. The paper discusses the importance of ornithopters' low-speed handling capabilities and their resemblance to birds in military spying applications. It also explores their potential in agriculture for pest control and in airports for bird deterrent purposes. The methodology of the project is described, including the design of the ornithopter with a transverse shaft gear mechanism and lightweight materials for optimized flight performance. Aerodynamic calculations are conducted to ensure proper design considerations, and the bird's hardware is assembled. The integration of a camera and the use of a flight controller contribute to the successful implementation of flight and surveillance capabilities.

Overall, the research paper provides insights into the design, development, and practical applications of the Spy Bird, showcasing its potential for aerial surveillance in military operations.

**KEYWORDS**: Ornithopter; Aerodynamics; Wing Structure; Control System; Frame Design; Electronics and Avionics

## I. INTRODUCTION

The field of aerial robotics is undergoing a transformative shift towards the development and utilization of bio-inspired aerial robots. These robots seek to replicate the exceptional capabilities observed in animals and insects, aiming to enhance agility, maneuverability, sensory perception, and adaptability. By drawing inspiration from nature, researchers and engineers are unlocking new possibilities for various applications, including search and rescue missions, environmental monitoring, and surveillance tasks. However, achieving a robotic platform that truly emulates the behavior of real birds poses significant challenges.

One of the primary challenges lies in our limited understanding of the aerodynamics of the entire robot and the need for suitable actuators that meet the design requirements. Additionally, the perception systems of these robots play a crucial role in gathering environmental information, enabling vital tasks such as localization, mapping, and object identification. Overcoming these constraints is essential for advancing the development of bio-inspired aerial robots.

In the realm of aerial robotics, selecting perception sensors is constrained by factors such as size, payload, and energy consumption. Ornithopters, in particular, face additional limitations due to their aerodynamic requirements, necessitating careful consideration in sensor choices. Moreover, the dynamic behavior of flapping wing robots presents unique challenges for vision-based perception, including vibrations and motion blur caused by fast flying maneuvers. Traditional vision sensors may struggle with strong changes in illumination, further complicating perception. Integrating sensors robust to these perturbations, such as event-based sensors, may offer a solution.

The aerodynamic characteristics of birds in flight provide distinct advantages over propeller or rotor-driven miniature air vehicle (MAV) designs in certain applications.

### A. Overview

This paper primarily focuses on the mechanical design aspects of mechanisms and wings, with emphasis on a flapping wing air vehicle weighing approximately 800g. Rather than providing an exhaustive list of all existing designs, this paper aims to familiarize newcomers with representative designs and their distinguishing features. By studying existing designs, future designers can adopt successful features and address design challenges for the further advancement and practical deployment of flapping wing vehicles. In summary, this paper presents an overview of the advancements, challenges, and design considerations in the field of bio-inspired aerial robotics. Through the exploration of existing designs and their unique characteristics, we aim to inspire future innovations and address design limitations to propel the field forward.

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**B. Problem definition**

Surveillance drones used in warfare face the disadvantage of being easily detected, tracked, and targeted by enemy forces. Sophisticated technology and countermeasures pose a significant threat, leading to potential destruction or loss of capabilities, which hampers military intelligence gathering and surveillance efforts.

Spy birds, despite their own limitations and challenges, offer a viable alternative to drones in specific scenarios. Their unique characteristics make them suitable for covert surveillance, enhanced maneuverability, and reduced detectability.

Achieving balanced aerodynamics involved meticulous selection of materials and intricate part design in constructing the bird. For instance, increasing the battery's capacity (mAh) adds weight, which becomes a challenge when designing a bird with an extended flight duration. Balancing the need for higher capacity (mAh) for longer flights with weight constraints is crucial in optimizing the bird's battery requirements.

**C. Objective**

1. To conduct precise aerodynamic calculations and carefully select appropriate materials and design mechanisms to ensure successful flight of the bird.
2. To design and integrate systems that enable the bird to perform controlled flight over a specific area while capturing and transmitting real-time video data back to the base camp.

## II. RELATED WORK

Ornithopters, which are aircraft that achieve flight by flapping their wings, have received less attention in research compared to fixed-wing aircraft. The field of ornithopter design is relatively sparse, with limited contributions and advancements. Notably, passionate hobbyists and enthusiasts like Sean Kinkade have played a significant role in exploring and pushing the boundaries of ornithopter technology.

Kinkade, a designer known for his radio-controlled ornithopters, has created models of various sizes, including both smaller and larger ones based on the Park Hawk, which served as the foundation for the Kestrel. Additionally, Kinkade holds a patent for his design. However, obtaining these ornithopters and their plans can be extremely challenging for interested individuals. The hobbyist community is actively developing original ornithopter designs, often drawing inspiration from Kinkade's work. However, there is a limited amount of published research available. Some designs explore additional wing degrees of freedom, and the Robot Locomotion Group has developed a wing design with variable amplitude. The aerodynamic properties of this type of ornithopter have been extensively analyzed using a motion capture system by Robyn Harmon from the Morpheus Lab at the University of Maryland. Additionally, the Morpheus Lab has been involved in researching the control mechanisms for simple ornithopters. Similar results have been achieved by the University of Arizona, which has been working with a 74cm wingspan ornithopter. Both projects prioritize lightweight onboard computers to ensure the aircraft's flight capability.

James Delaurier's work has been instrumental in the design and analysis of larger scale ornithopters. Notably, there has been a long-standing project to build a piloted ornithopter, which, as of July 8, 2006, achieved several seconds of sustained flight.

## III. METHODOLOGY

**A.** *Research and Conceptualization:*

When considering the construction of a robot ornithopter, a layered system becomes evident. At the core is the mechanical ornithopter system, with its primary requirement being acceptable flight performance. In this initial stage, "acceptable" means the ability to sustain flight under calm conditions while accommodating the added weight of sensors and a computer. Derived from this fundamental requirement are several secondary criteria. As a research platform for controls, it is expected that the ornithopter will experience crashes initially, making crash survivability and reliability essential, particularly in less severe conditions. Designing points of failure to isolate damage to easily replaceable parts in the field is emphasized. Additionally, all systems should be easily integrated with the computer controller. The sensing and computing equipment carried by the mechanical platform is generally considered secondary but plays a crucial role in the intended research use of the ornithopter. Sensors are necessary to measure as much of the ornithopter's state as possible for system identification and control purposes. While absolute position in space is not critical at this stage, the body's orientation and the position of the wings and tail relative to the body are highly important. Although the project requirements may seem straightforward, the engineering process to achieve them involves numerous iterations to develop final specifications, followed by design iterations to bring those specifications to fruition.

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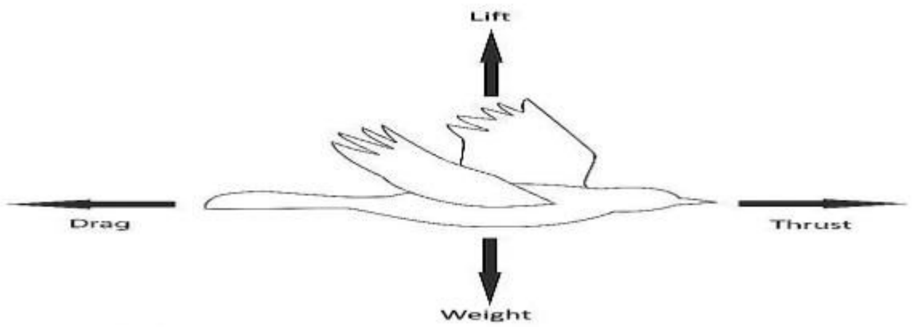
**B.** *Principle of an ornithopter*

Flight is a natural phenomenon observed in birds, and it is governed by the principles of physical science. The ornithopter, like birds, achieves flight by balancing four fundamental forces: lift, thrust, drag, and weight. These forces interact to enable and control flight, as depicted in the Figure.




Lift: Lift is the upward force generated by the wings of an aircraft. It is produced by the difference in air pressure between the upper and lower surfaces of the wings. Wing shape and angle of attack are crucial in generating lift, allowing the aircraft to overcome gravity and stay airborne.
Weight (Gravity): Weight is the force exerted by gravity on an aircraft, acting in the downward direction. It is countered by the lift force. For level flight, lift must be equal to or greater than the weight.
Thrust: Thrust is the forward force that propels an aircraft through the air. It is generated by engines or propulsion systems, enabling the aircraft to accelerate, decelerate, or maintain speed. Ornithopters achieve thrust through various means, such as flapping wings.
Drag: Drag is the resistance encountered by an aircraft as it moves through the air. It opposes the aircraft's forward movement and is caused by factors like air resistance, friction, and turbulence. Reducing drag is essential for fuel efficiency and optimal performance.
To achieve and sustain flight, the forces of lift and thrust must overcome the forces of weight and drag, respectively. By carefully controlling these forces, pilots or automated systems can maneuver and control the aircraft.
It's important to understand that the interaction of these forces is influenced by factors such as aircraft design, altitude, air density, speed, and flight maneuvers. Aerodynamics and the science of flight play a significant role in comprehending and optimizing these forces for safe and efficient flying.

## IV. DESIGN AND IMPLEMENTATION

1. **Wing Structure:**
   The selection of lightweight materials such as carbon fiber, balsa wood, or lightweight composites is made to construct the wings. The wings are covered with flexible materials like fabric or thin films to facilitate proper flapping motion. We have used ripstop polyester and carbon fiber rod for the frame of the wings.
   The wing design selected for the Spy Bird is based on a well-established design by Sean Kinkade, known for its successful implementation in various ornithopter designs. This demonstrates the scalability and effectiveness of the wing design.
   Drawing from years of development and expertise in this wing design, our project can prioritize areas where we have extensive experience, such as the gearbox, electronics, and controls. This allows us to concentrate our efforts on optimizing these components for the Spy Bird's performance and functionality.

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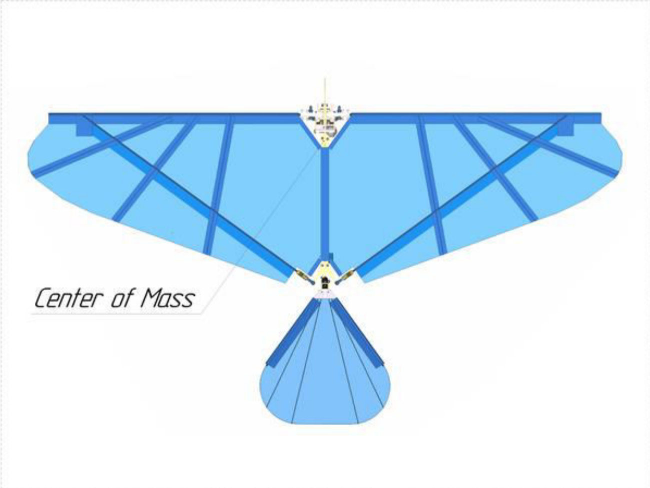


Wing and tail structure

2. **Flapping Mechanism:**

A suitable mechanism is chosen to convert rotary motion into the flapping motion of the wings. Options such as a crank-slider mechanism, four-bar linkage mechanism, or other appropriate mechanisms are considered. The mechanism is powered by an outrunner dc motor.

To achieve an optimal power-to-weight ratio, a highly integrated design is necessary. The analysis of the components involved in this design can be broken down effectively.

In our transverse shaft design, we require two end-gears (left and right driven D gears) to control the movement of the wings. The desired flapping frequency for the ornithopter's wings is 5-7 strokes per second, which determines the rotational speed of these gears.

To attain the required rotational speed, we utilize two pairs of gears: gear A + gear B and gear C + gear D. This configuration creates a gearbox with two stages of reduction. The transmission ratio for the first gear pair (gear A + gear B) is 10:40, while for the second gear pair (gear C + gear D), it is 10:60. The choice of the number of teeth for these gears is determined by the pinion gears (gear A and gear C). As for gears B and D, they are produced through 3D printing, allowing flexibility in selecting the number of teeth. All gears have a module of 0.5.

The driven gear A is attached to the motor shaft, while gears B and C are rigidly mounted on the shaft, ensuring they rotate at the same speed. The total reduction ratio is the product of the first and second stage reduction ratios. Let's calculate the total reduction ratio.

(60 / 10) * (40 / 10) = 24, indicating a total ratio of 1:24.

If the electric motor is powered by 7.4V, gear A rotates at a rate of 10360 revolutions per minute or 172 revolutions per second. Considering the total reduction ratio, we can determine the speed of the end-gears (left and right driven D gears).

172 / 24 = 7.16 revolutions per second.

This value corresponds to the number of wing strokes per second at a 7.4V supply voltage and no load. It falls within the desired range of 5-7 strokes per second. If the flapping frequency is too high, we can reduce the motor speed, and if it is too low, we can attempt to increase the voltage by using a 3S (11.1V) battery.

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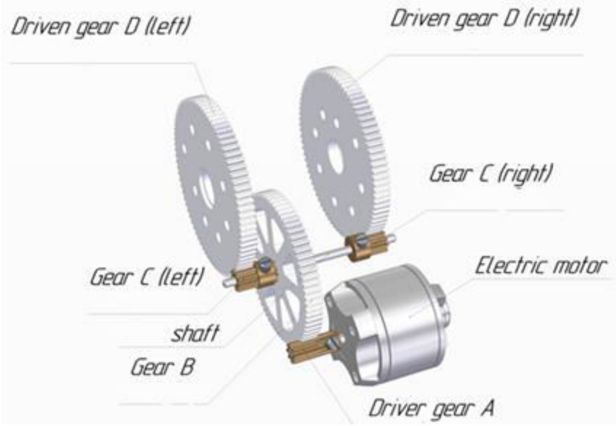
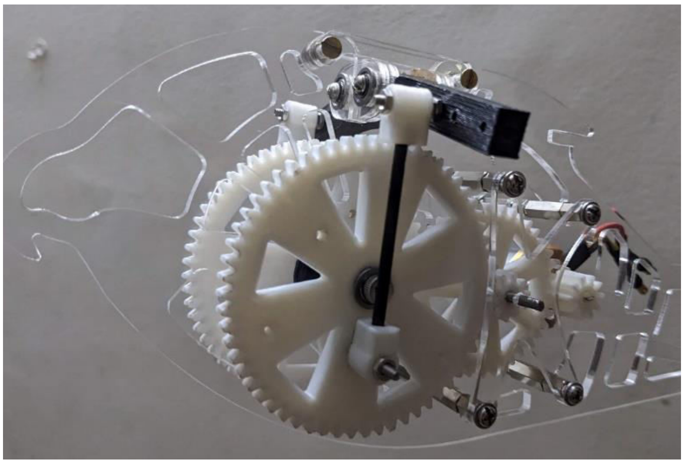


Gear Mechanism


Assembly of the gearbox used as the flapping mechanism

To increase the torque and reach the necessary flapping frequency, we are using a gearbox. In this case, we can take a weaker motor with a higher revolution per minute (rpm) value. Considering the ornithopter dimensions, the 300 - 400 sized electric hobby motor should fit perfectly. Hobby motors of this size can be brushed or brushless. Basically, you can find them in medium-sized RC boats and helicopters. The motor we are using: A2212 1400KV BLDC outrunner motor. Paying attention to the important detail, we needed an out-runner motor. Mounting holes of the motor must be on the same side as the output shaft. So, housing which is close to the output shaft has to be immovable.

Main motor characteristics:
Output shaft diameter: 2.3 mm;
Max current: 22A / 20S;
Voltage: 2 - 3S;
Dimension: 26mm x 27mm, 41mm;
Weight: ≈ 39g;

3. **Power Source:**
The power source is chosen based on the ornithopter's size and intended use, considering factors like electric motors, servo motors, etc. Power requirements and weight limitations are taken into account during the selection process. We have selected an 850 mAh LiPo battery as the power source.
Battery used:
850mah 2s LiPo battery,7.4v
Main battery characteristics:
2 Cells, 7.4V;
Capacity: 850mAh;
Discharge Rate: 30C;

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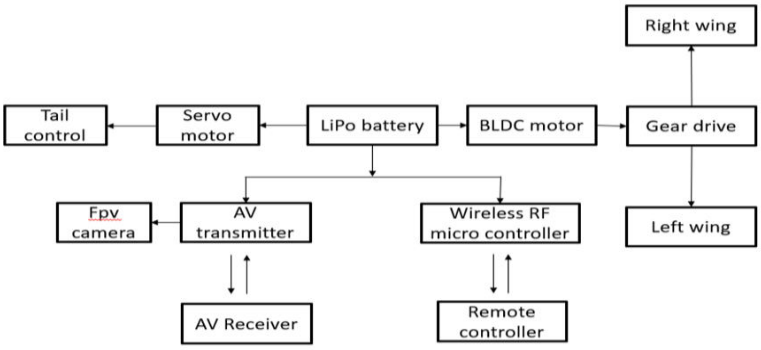
Weight: ≈ 56g;

4. **Control System:**
A control system is integrated to regulate wing motion, ensuring stability and maneuverability. Control surfaces like movable tail structures, ailerons, or other mechanisms are utilized to adjust wing motion. Precise control is achieved using servos, actuators, or other suitable mechanisms.


Tail design which is mainly responsible for control of flight



Control System

5. **Structure and Frame:**
A sturdy frame or structure is constructed to support the wings, flapping mechanism, power source, and control systems. Lightweight materials such as carbon fiber tubes, aluminum, or other suitable materials are used for this purpose. We have used Acrylic sheet for the frame.


Frame / Body of the ornithopter

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6. **Aerodynamic Design:**

The ornithopter is designed with consideration of aerodynamic principles to optimize flight efficiency. Factors such as wing shape, area, aspect ratio, and other aerodynamic properties are taken into account to enhance performance and stability.

The wing design for the Spy Bird is based on the characteristics observed in birds. Long, narrow wings provide stability and enable steady long-distance flight, while short, broad wings allow for quick changes in direction. The flapping rate of bird wings is determined by wing area, with different bird species exhibiting varying frequencies of wing flaps per second.

The Spy Bird falls within a moderate range of wingspan (1200-1400 mm) and is designed to flap at a rate of 5 to 7 times per second, with a flight weight of approximately 400 g.

Balancing the weight and center of gravity of the ornithopter is crucial for flight safety and stability. The structural movement and unsteady fluid dynamics associated with flapping flight pose additional complexities compared to fixed-wing flight. Flapping flight involves two stages: the downstroke or power stroke, which generates thrust, and the upstroke or recovery stroke, which provides some upward force. The angle of attack of the wings varies along the wingspan to maintain proper lift and propulsion. To achieve the desired flapping rate, a suitable flapping mechanism will be designed for the ornithopter.

In summary, the Spy Bird's design includes a wingspan of approximately 1200-1400 mm, a flapping rate of 5-7 Hz, and a flight weight of around 400 g. Careful consideration of weight distribution and wing dynamics is essential for successful ornithopter flight.

- Wingspan ≈ 1200 - 1400 mm;
- Flapping rate ≈ 5 - 7 Hz;
- Flight weight ≈ 400 g.

7. **Electronics and Avionics:**

Depending on the complexity of the ornithopter, electronics and avionics components are incorporated for control, stability, and data collection. This may include flight control systems, sensors, onboard computers, and communication systems as required.

Camera and surveillance :
For surveillance, we are using an Fpv camera with transmitter
Transmitter
characteristics:
Transmitter 600mW/48CH >5km (open area).
Frequency control: built-in frequency and phase lock loop.
Transmitter module connector: Female RP-SMA.
Antenna connector Male RP-SMA
Supply Voltage: 7-24 V
Current: 220 mA.
48 CH is compatible with all FPV 5.8g receivers

Receiver characteristics:
Model: ROTG01
Name: UVC OTG FPV Receiver
Channel: 150CH
Power Supply: 5V (by smartphone)
Connector: SMA Female
Fpv camera characteristics:

Name :1000TVL 1/3 CCD 110 Degree 2.8mm
Lens Mini FPV Camera
Power Consumption: 55mA@ 5v
Format: NTSC/PAL (Free switch)
Lens: 2.8mm IR coated FOV: 110°
With WRD function in the default

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To control the ornithopter we use:
Flysky FS-i6-M2 2.4GHz 6-Channel Transmitter
This transmitter transmits information to the flight controller and the operator can control the ornithopter through this transmitter

Building an ornithopter is a complex task that requires a combination of engineering knowledge, aerodynamic principles, and practical skills. It often involves iterative design, testing, and refinement to achieve successful flight. Consider consulting resources, books, or seeking guidance from experts in the field to enhance understanding and increase the chances of success.

## V. RESULTS AND DISCUSSION

The results of our project can be summarized as follows:

1. Model Completion:

The model was successfully completed after extensive research and material search.
All necessary aerodynamic considerations for an ornithopter were incorporated into the design.

**2.** Constraints and Limitations**:**

Lack of Resources: There were limitations in obtaining the exact materials required for successful flight due to resource constraints.
Lack of Funding: Financial constraints limited the availability of resources needed for the project.

3. Adjustments in Design:

Due to the unavailability of specific materials, certain design modifications were made to adapt to the available materials.
These modifications resulted in an increased weight of the bird.

4. Flight Challenges:

Inability to Achieve Flight: Despite the design efforts, the increased weight of the bird prevented successful flight.
Requirement for Higher Power: To generate sufficient lift, higher motor power and battery capacity were necessary.
Lighter Materials Needed: Alternatively, the use of lighter materials could have facilitated flight, but they were not attainable due to constraints.

5. Project Outcome:

Due to financial and resource limitations, the project could not achieve the desired flight capability.
Given the constraints, this represents the final outcome of the project.

| | |
|---|---|
| Total weight of the bird | 850-900 grams |
| Gear ratio to the motor | 1:24 |
| Flapping frequency of the wing | 5-7 flaps per second |
| Total wingspan | 1200 mm |
| Length of the bird | 800 mm |
| | |

Table 1 Project outcome

All the aerial vehicles are weight sensitive, especially the ornithopters. Because of the unavailability of exact materials, we had to compromise with other materials. This has caused to increase the weight of the ornithopter.
The unavailability of gears has necessitated a change in the design of the ornithopter.
Due to the increased weight, it is more difficult for the ornithopter to achieve lift.
Heavier weight makes the ornithopter more difficult to provide enough lift, increasing the wingspan might solve the issue but the motor we are currently using are unable to provide such amount of force
During the harsh conditions of a war, lack of information about enemy camps can get the soldiers subjected to sudden encounters of the enemy and can increase the chances of failing the mission and most importantly leading to casualties
The spy bird can get information of the enemy camps and any other sudden attacks from the enemy and can get the soldiers prepared for any previously mentioned attacks in advance.

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The defense requires an advantage over the enemy to be prepared and render a better performance overall.

## VI. CONCLUSION AND FUTURE WORK

In conclusion, weight sensitivity poses significant obstacles in the design and functionality of ornithopters. Compromises were made in material selection due to unavailability, resulting in increased overall weight. Limited gear options required design modifications, hindering the achievement of necessary lift. Addressing the weight issue through increased wingspan is limited by the current underpowered motor. Acquiring appropriate materials and resources is crucial for successful ornithopter development. Overcoming these challenges requires further research. This project emphasizes the importance of planning, resource availability, and weight dynamics in designing ornithopters. Future efforts should address these limitations to unlock ornithopter technology's full potential across applications. The Spy Bird has significant potential for defense applications. A scaled-up version has been designed to meet performance and weight constraints. The ornithopter is capable of carrying an FPV camera and can be further enhanced with advanced sensors. Its lightweight and optimized design make it suitable for surveillance missions. Future efforts should focus on improving performance, payload capacity, and exploring additional features. Ornithopters show high propulsive efficiency and have applications in espionage, airports, and wildlife preservation. Their maneuverability and low noise make them valuable in covert operations and bird control. As research progresses, ornithopters hold promise for diverse domains.

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