# Development and Optimisation in Ornithopter Drone

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**ABSTRACT**

Biological inspired robotics has emerged as an important area within the field of robotics. People dreamt to fly like a bird since the earliest civilizations. The study of robotic bird is the race to overcome natural flight through mechanical means. Numerous devices have been developed with an objective to achieve optimum natural flight capabilities since the concept of ornithopters or Flapping Aerial Vehicles (FAVs) flourished.

An ornithopter (from Greek ornithos "bird" & pteron "wing") is an aerial vehicle that flies by flapping its wings, i.e. it can also be defined as an aircraft that produces its thrust & lift by virtue of flapping wings. The principle of operation of an ornithopter is the same as an airplane; forward motion through the air lets the wings to deflect air in the downward direction, producing lift but the flapping motion of the wings takes the place of a rotating propeller. On the contrary, the aerofoils of an ornithopter have a flapping or oscillating motion, instead of a rotary motion as airplanes and helicopters employ. The wings of an ornithopter have a combined function of providing both lift & thrust.

**Keywords**: Ornithopter, Flapping Wing, Articulated Wings, Flapping Air Vehicles (FAVs), Robotic Bird.

## 1. INTRODUCTION

Nature has always inspired and fascinated humans. Humans try to imitate the ways and functioning of nature to achieve perfection. People dreamt to fly like a bird since the earliest civilizations. The study of FAVs is the race to overcome natural flight through mechanical means. However the efficiency, maneuverability, flight endurance limit, as well as the aerodynamic stability of a natural flyer is almost impossible to achieve. An Ornithopter or a FAV is a mechanical device that uses its ability to flap wings as a locomotive agent.

The ornithopter is powered by a brushless motor, couples with a lightweight custom-made high ratio gearbox, the output of which is connected to a crank which actuates the wings whose hinges are outboard from the main body. Flapping rate/frequency is controlled by varying the motor speed with an Electronic Speed Controller (ESC), which in turn is controlled by the RC receiver. The tail is used to provide direction to the ornithopter & is actuated by 2 servos in an inverted V-tail setup. All the electronics are powered by a 3-cell lithium polymer battery & controlled from the RC transmitter by the operator. Some typical ornithopters are shown below.

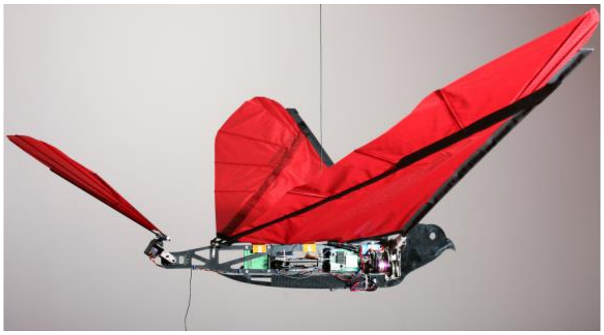

**Figure 1**: **Ornithopter designed by MIT's Robot Locomotion Group**

**Figure 2: Dual-winged Ornithopter**

## 2. LITERATURE REVIEW AND OBJECTIVE

Kadlag Vishwajit et.al. [2021] had published their work, "Unmanned Aerial Vehicle (Ornithopter Drone)". In their work, they focused on-The purpose of this paper is to identify

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a longitudinal linear model of an ornithopter by automated flight tests. Flight tests were conducted outdoors, and an avionic board with sensors was installed on-board for measuring angular rates, Euler angles, and a total velocity. For accurate flight test, automated signal input is designed for elevator deflection: doubletand multi-step 3211 maneuver. During a cruise flight, the ornithopter normally had oscillation which is generated by flapping motion of the main wings. Fast Fourier transform(FFT) is used for analyzing flight data in a frequency domain, and a Butterworth filter is designed to filter the corrupted data by the flapping motion. The structure of the ornithopter linear model is assumed to be similar to a fixed-wing aircraft which has a periodic oscillation because it has similar control surfaces except the flapping motions. For system identification, unknown parametersare estimated by unconstrained nonlinear optimization.

Anurag Kale et.al. [2020] had published his work, "Design and Fabrication of an Articulated Ornithopter". In their work, they focused on-The first stage, on which this paper focuses, is to create a simulation of the ornithopter on the computer and use a genetic algorithm to evolve successful flight and control patterns. Once this has been accomplished, mechanical designs will be partially evolved to help aid in the physical design of ornithopters. Then control patterns for this machine will be re-evolved in hardware in a similar fashion used for the simulated models to produce a real flapping ornithopter.

Siddharth Joshi et.al [2018] had published his work, "Robotic Bird". In their work, they focused on-After studying and performing trials here are the areas that can be focused upon: -Fixed amplitude and variable frequency flapping motion of wings. -Development of wing-twisting mechanism -Progression in the technique to reduce negative lift generated during the upstroke of wing(s). -Provision of increased versatile maneuvering capabilities. -Innovating techniques for independent successful take-off and landing techniques. -Only a marginal number of the models developed today, possess autonomous, robust flight with onboard power source as well as a camera vision feed. -Inventing techniques that allow backward-flying trends.

Prof. Amisha Pathak et.al [2017] had published his work, "Ornithopter with Articulated Wings". In their work, they focused on-Bird-like appearance renders it very useful for surveillance & defense purposes which require the aircraft to blend into its surroundings. As the wings reciprocate at a low frequency hence blade losses are minimized & no shock waves are produced as is the case with conventional aircraft. It's a highly efficient machine hence longer flight time on a smaller battery. Extremely light weight, hence easy to transport. Large wing span is needed for the ornithopter to generate enough thrust for propulsion. The ornithopter has low weight carrying capacity. The ornithopter can be easily destabilized by strong winds unless sophisticated electronics are used.

Zachary John Jackowski, [2009] had published his work, "Design and Construction of an Autonomous Ornithopter". In their work, they focused onIn recent years the subject of flying vehicles propelled by flapping wings, also known as ornithopters, has been an area of interest because of its application to micro aerial vehicles (MAVs). In order to better study the control of flapping wing flight we have developed a large scale ornithopter called the Phoenix. It is capable of carrying a heavy (400gram) computer and sensor package and is designed especially for the application of controls research. The design takes special care to optimise payload capacity, crash survivability, and repair abilities.

Objectives-
1. Bird like flight involving take off, gliding and landing
2. Light weight and strong body design
3. Provision of landing and take-off mechanism.

## 3. MATERIALS AND METHODS

3.1 Component Description:

Motor: - The entire ornithopter is built around the motor. Major factors for proper selection are kV, size & power rating. The kV of the motor is the rpm at which it'll spin per volt. The lower the kV, the stronger the motor & as a result, only a lower gear ration is needed. Size is designated by a 4-digit number. The motor shouldn't be over-powered as it adds momentum in crashes. Lastly, the motor must be powerful enough to satisfy the needs of the ornithopter.


**Figure 3: Brushless DC motor**

Battery: - The battery must have a good power-to-weight ratio & should be able to discharge a large amount of current fairly quickly. Large batteries weigh a lot & not only decrease the thrust-toweight ratio but also increase the minimum flapping frequency of the ornithopter. Number of cells in the battery is also important as there are limits to this parameter on both the motor & ESC, which is clearly listed in their manuals.


**Figure 4: Lithium polymer Battery**

ESC: - ESC controls the speed of the motor as per the signal given from the RC receiver. The ESC must match the motor. The ESC is rated for the maximum amperage draw of the motor at full load. This part, however, can be over-rated as it just adds safety to the ornithopter.

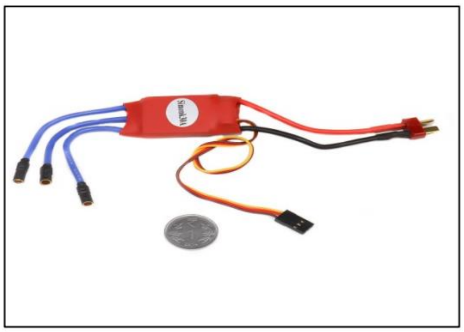

**Figure 5: Electronic Speed Controller**

Transmitter & Receiver: - This system is responsible for relaying the commands given by the operator through the transmitter to the receiver via a frequency band. It's the central & most fundamental component of the whole RC ornithopter, because it crashes if signal is lost. 3 channels are must for the ornithopter to operate.


**Figure 6: Transmitter & Receiver**

Servo motors: - These small motors have very limited but extremely accurate range of motion. They can be precision controlled & have variable movement. One servo is needed for every control surface. Servos will move control rods which are connected to control horns on the control surfaces.

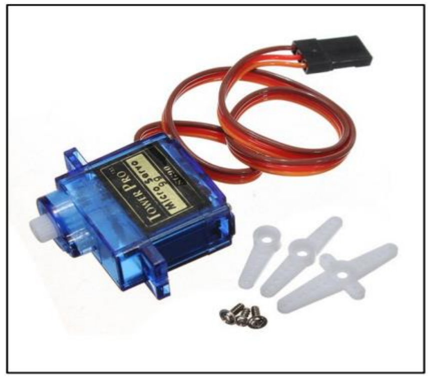

**Figure 7: Servo motor**

### 3.2 Aerodynamic Principle

The principles that define the behavior of flight characteristics of a bird or any other aerial organism are defined as the aerodynamic principles. A number of factors are involved in governing the flight of a bird. These factors include the free-stream velocity, angle of attack (AoA), Reynolds's Number, wing membrane flexibility, aspect ratio, boundary-Layer flow, etc

Majorly, four types of forces affect the flight motion – weight, in downward direction; lift in upward direction or perpendicular to the direction of relative upstream velocity; thrust in the direction of flight; and lastly, drag force in the direction opposite to flight motion. Weight of the component is balanced by lift force, and thrust balances the drag force, during a cruising flight.

Lift force is generated by the use of wings, which may be fixed (ailerons) or flapping. Magnitude of lift generated is significantly dependent upon the upstream velocity, but is also a function of density of the surrounding fluid (air), viscosity, square of the flapping wing velocity, surface area of the wing in contact with boundary layer of flow, as well as the extent of aero dynamicity of the body. So lower the air density, lighter should be the design of mass system. Additional affecting factors include compressible nature of fluid (air), wing size and AoA. Angle of Attack (AoA) is defined as the angle between the direction of relative free stream velocity, and the chord of the wing. It is thus understood that in order to generate positive lift, lift force produced should be higher than weight force of the model. Upward stroke of the wing gives negative lift which is undesirable and so projected surface area is decreased. Also, the end of upstroke generates additional negative lift due to the change in velocity over wing surface. During the down stroke of the wing, the AoA is negative, while it is positive during the upstroke, which thus results into minimum negative lift. The sign of AoA flips at the extreme flapping positions in the Flapping Plane.

Secondly, is the drag force, which is produced due to body shape, amount of surface area contributing to the boundary layer flow, and the critical angle of attack. Above the critical angle of attack (≈ 15 degrees) results into sudden increase in the drag force on the body which causes it's stalling. Thus, the drag is an inevitable aerodynamic force which can only be reduced; may be by altering the airfoil section, or smoothening of surface layer, thus reducing friction, as well as reducing the chord length so that minimum amount of surface area of wing is in contact with flowing air. The drag force along with lift force perpendicular to upstream velocity induces a resultant lift which reduced the AoA to an effective lesser AoA, as depicted in the Fig.4.1.

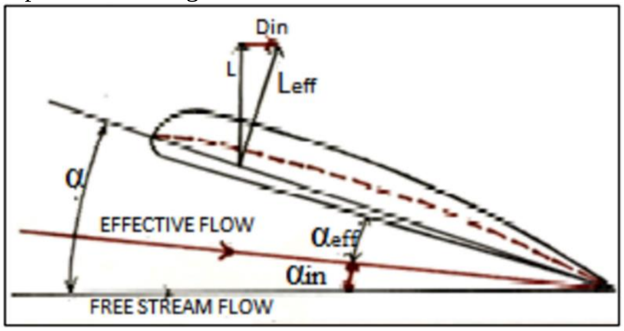


**Figure 8: Effective AoA in airfoil Section**

## 4. RESULTS AND DISCUSSION

### 4.1 ADVANTAGES OF ORNITHOPTERS OVER CONVENTIONAL AIRCRAFT

1. Bird-like appearance renders it very useful for surveillance & defence purposes which require the aircraft to blend into its surroundings.
2. As the wings reciprocate at a low frequency hence blade losses are minimized & no shock waves are produced as is the case with conventional aircraft.
3. It's a highly efficient machine hence longer flight time on a smaller battery.
4. Extremely lightweight, hence easy to transport.

### 4.2 DISADVANTAGES OF ORNITHOPTERS OVER CONVENTIONAL AIRCRAFT

1. Large wing span is needed for the ornithopter to generate enough thrust for propulsion.
2. The ornithopter has low weight carrying capacity.
3. The ornithopter can be easily destabilized by strong winds unless sophisticated electronics are used.

## 5. CONCLUSIONS

Through the comparative study of various ornithopters and UAVs, certain observations are made. Increased research, development and interest in the field of UAVs since the last two and half decades has given birth to devices with unmatched similitude with the natural flyers, however, scope of research is still seen in some areas.

Majorly, the already developed FAVs exhibit fixed amplitude and fixed flapping frequency trends. Incorporating the former characteristics allows for variable climb and thrust during flight as per the requirement. We also know that upward stroke results into negative lift, and thus, reducing the effective wing surface area during upward stroke drastically lowers the negative lift. This can be done by twisting the wing during upward motion. Numerous other techniques can be researched with the objective of reducing the anti-lift. A natural bird-flight like maneuverability is still in myth in this field and the example of Festo SmartBird is the closest yet to this goal. Although the Festo claims to have achieved autonomous flight successfully avoiding obstacles, it is not yet capable of independent take-off and landing. In a nutshell, only a marginal number of the models developed today, possess autonomous, robust flight with onboard power source as well as a camera vision feed. It was also observed that none of the ornithopters possessed backward flying ability which can prove to be a significant need during surveillance and rescue operations in narrowed places like tunnels, and holes. Space constraints may not permit turning of ornithopters and thus, backward flying helps.

Thus field of robotic bird being an emerging one, has plenty of future research scope. Hereby are the areas that can be focused upon:

1. Fixed amplitude and variable frequency flapping motion of wings.
2. Progression in the technique to reduce negative lift generated during the upstroke of wing(s).
3. Provision of increased versatile maneuvering capabilities.
4. Innovating techniques for independent successful take-off and landing techniques.
5. Only a marginal number of the models developed today, possess autonomous, robust flight with onboard power source as well as a camera vision feed.
6. Inventing techniques that allow backward-flying trends.

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## NOMENCLATURE

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|---|---|---|
| *AoA* | Angle of Attack | (°) |

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