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Design And Construction Of An Ornithopter

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Abstract

The first ornithopters capable of flight were toys built in the late 19th century in France. Large-scale, piloted ornithopters were first developed in the early 20th century. Piloted ornithopters come in two basic categories: engine-powered and human-powered. In this paper, we are concentrating on the procedure for the design and fabrication of flat wing ornithopter with the flapping frequency of 6Hz and wingspan of 1m. While designing an ornithopter chronological sequence should be maintained, in that we have to select flapping frequency according to predicted weight then by selecting a suitable motor we have to design gearbox for the required reduction ratio. After that, while designing wing there are different parameters like the coefficient of drag, aspect ratio, etc. optimum selection of these parameters is important. The designing tail is important as it is responsible for pitch and yaw control, during the design of tail stability and control for flight are the parameters to be considered. After the design of mechanical components selection of electronic components like battery, ESC, servomotors, controller, and receiver are selected. In this paper, we have discussed the most advantageous types of these electronic components.

Keywords *—Ornithopter, Micro-Aerial Vehicle (MAV), Flapping wing design, Gearbox design, Flapping mechanism*

I. INTRODUCTION

An ornithopter is a machine designed to achieve flight by flapping its wings like a real bird. The word "ornithopter" comes from the Greek words for "bird" and "wing". Nature-especially animals- have been the foremost inspiration for the design of many of the objects we use in our daily lives. From items as simple as forks to sophisticated airplanes, humans have continually looked to nature for clues. While some of the efforts to mimic nature have led to great successes, others have failed to materialize into practical outcomes. One such futile effort is the ability to fly like other volant animals in nature. This ability has always intrigued humans for a very long while until the invention of airplanes which although are excellent and reliable in many respects, do not quite satisfy that desire to reach for the skies and soar like birds, bats, and insects. The insatiable quest to fly like birds has recently led to the design of various micro-aerial vehicles (MAV) modeled after smaller insects and birds as well as medium-sized ornithopters-a general term for flapping-wing propelled aircraft.

Flapping wing flight like fixed-wing flight works based on the principle of action and reaction as described by Newton's third law of motion. A flying body generates lift by displacing a mass of air

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downwards and thrust by displacing a sufficient mass of air in the opposite direction to the desired direction of flight.

II. Design And Fabrication Of An Ornithopter

A. Gearbox and Flapping Mechanism

The most critical part of the ornithopter is the drive mechanism that converts the electric power from the battery to the flapping motion of the wings. This system is the most complex to design and fabricate because it must withstand very large forces that reverses direction several times a second while at the same time it needs to be extremely light and durable. Because of the loads, it must be made from durable material which makes it beneficial to perform careful analysis and trim as much weight as possible. The drive system can be further broken down into four sections, the electric motor, a gear reduction stage, a linkage to convert the high torque rotation into a reciprocating motion and the connection to the wing spars. Referring to different research papers, we have concluded to take a flapping frequency of 6 Hz for flat wings [1]. Now to obtain 6 Hz frequency at wing we decided to use a motor with 7500 RPM (125 Hz) and for required speed reduction, the gearbox is designed [2].

Gear reduction for outer runner motor having specification speed of 7500 RPM should be,

$$6 \text{ Hz} = 5 \times 60 = 360 \text{ rpm} \qquad\qquad i = 7500 / 360 = 20.83$$

Where,

i = total reduction

As i lies in between 6 and 36, a 2-stage gearbox will be required,
Speed reduction in each stage,

$$i' = \sqrt{i} = 4.5$$

*module was assumed to be 1 mm (as the gears of module 1 are easily available)
Accordingly, calculations were done and specifications of required gears were obtained, as specified in the following table,

TABLE I
SPECIFICATION OF GEARS

GEAR NO.	PITCH DIAMETER	NO. OF TEETH	MODULE	QUANTITY
1	10	10	1	1
2	45	45	1	1
3	11	11	1	1
4	50	50	1	2

The shafts used were 3mm mild steel shafts with push-fit. For the flapping motion of the wing, we select a simple four-bar mechanism [1]. Crank and wing shoulder (rocker) of mechanism must be strong for sustaining the large force and connecting rod should have some flexibility so for that tie rod is the best option.

1) Material Selection for Components of Gearbox:
- Motor pinion – Mild steel
- Other gears – Nylon

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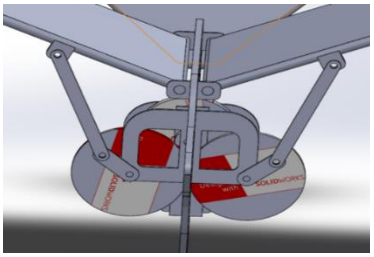
- Shaft – Steel
- Crank and connecting rod – Carbon fiber

2) Design of Gear Box and Flapping Mechanism in Solid-Works



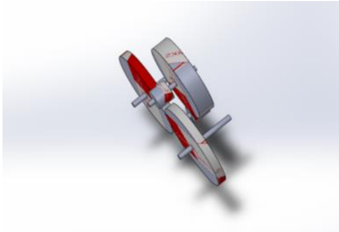


Fig. 1 CAD model of four-bar crank mechanism

Fig. 2 CAD model of Gearbox

3) Manufactured Gearbox and Flapping Mechanism

Fig. 3 Actual Gears

Fig. 4 Parts of the gearbox frame

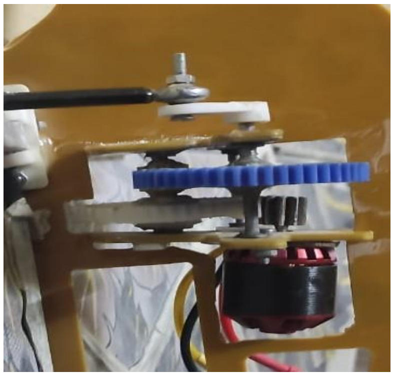


Fig. 5 Assembly of gearbox and motor

Fig. 6 Assembly flapping mechanism

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B. Wings

As with the flapping mechanism, there are many ways to build an ornithopter wing. The simple "membrane" type of ornithopter wing is the most commonly used. This is not only because it is easy to build. It is also the most consistently successful ornithopter wing design. The membrane wing consists of a spar, at the leading edge of the wing, and a membrane, which extends backward from the spar and attaches to the body of the ornithopter. Now as we have chosen membrane type of wing, the second important thing is to decide the dimensions of the wing. One of the key points to be considered while designing wings is the Aspect ratio. The aspect ratio is the ratio of the wingspan to the chord length. For the low aspect ratio (AR=1.2), the fuel consumption is high because of more drag force. Also, the low aspect ratio results in the low stability of birds during flight. All these disadvantages can be resolved by using a high aspect ratio (AR=12.5), But keeping the aspect ratio as high as 12.5 will give a very high value of wingspan, eventually, the size of the bird will be more, and a bird will be bulky [3]. Hence a moderate value of Aspect ratio, 5.6 is selected.

Considering different parameters of the frame, initial weight of the bird, and frequency of flapping the width of the wing is considered as 18 cm. and with the help of aspect ratio, the wingspan is calculated as 102 cm. with 2 cm as frame thickness, the length of each wing becomes 50cm. The process for calculating specifications can be seen in the section below [4].

First, the constants were set.

- Coefficient of Drag (C_d) = 2
- Density of air ($\boldsymbol{\rho}$) = 1.225 kg/m^3
- Acceleration due to gravity (G) = 9.81 m/s^2
- Maximum angle wing makes concerning the body ($\boldsymbol{\theta}$) = 0.5236 radians

The coefficient of drag was set as if the wing was a flat plate. This was done because the velocity of the wing is in the Y direction concerning the direction of the travel of Wing. Also, the surface area of the wing when looking straight at Wing's beak produces negligible drag. Therefore, the only source of drag will come from this flapping motion. Finally, values were calculated, Considering

- Wing Span (b) = 1 meter
- Chord Length (c) = 0.18 meter
- Initial Weight of Bird = 0.55 kg

1) *Drag Force (F_d) Was Calculated with The Following Equation:*

$$F_d = (\rho * C_d * c * b^3)/3$$

2) *Angular Momentum ($\boldsymbol{\omega}$) Was Calculated Using the Following Equation:*

$$\omega = \sqrt{M * G / F_d}$$

3) *The Torque (τ) Of the Wings Was Then Calculated:*

$$\tau = (\rho * \omega^2 * C_d * c * b^4)/8$$

4) *Power (P) In Watts Was Calculated:*

$$P = \tau * \omega$$

With the help of above standard equations, the drag force is calculated as 0.147 N, Angular momentum obtained is 6.05 rad/s, the value for the torque of wings is 2.01 N-m and the power required is 12.16 watts. Since the power of the available motor is 255 watts, the designed wings can withstand the

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drag force and the ornithopter can fly easily. The parameter for wings is now decided so the second most important thing is to provide proper support to wings. Support is a crucial part of wing design and needs to be provided so that the wing membrane won't get torn off. In this support structure, the spar is the part where all forces reaction gets transmitted.

For spars, we require high rigidity and stiffness where for membrane we require high tensile strength with less weight.

- Material selection for wing:
  - Spar – Carbon Fiber
  - Membrane – Nylon Fabric

Fig. 7 Carbon fiber rod (Spars) Fig. 8 Manufactured wing with 3D printed connectors

C. Tail

Steering is usually done by the tail. The wings can be used for steering, but this is less consistently successful and more difficult to implement. A simple elevator and rudder system is very effective for ornithopter steering. For a more birdlike appearance, though, a flat, triangular tail is more often used. The tail may swing out to the left and right sides so that the downforce of the tail causes a rolling moment on the ornithopter. Alternatively, the tail may rotate about its long axis. In this case, the downforce is redirected in a way that provides yaw control. Flat v shape design is used since it is consistently successful [6].

- Material selection for the tail:
  - Spar – Carbon Fiber
  - Membrane – Nylon Fabric

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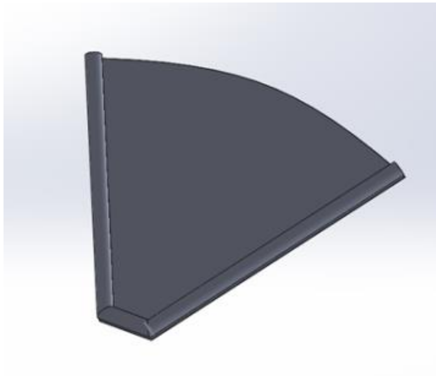

Fig. 9 CAD model of tail

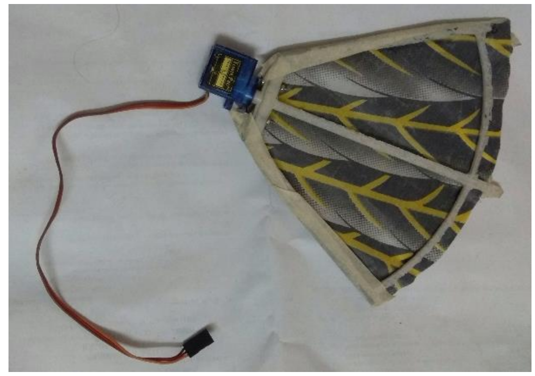

Fig. 10 Tail Assembly

D. Selection of Electronic Components

1) Motor

Most radio-controlled ornithopters are powered by an electric motor and battery. There are several types of electric motor that may be used in an ornithopter. The selection of motor type will depend on your specific project. The motor should be small in size. Big size motor weight a lot and weight can be very critical for the design. At the same time, the electric motor should be sturdy to provide enough torque to overcome air resistance.

In a brushless type motor, the electromagnets are switched on and off electronically, so there are no mechanical contacts which make the brushless motor more efficient. Hence, we have selected “Avionic C2830/12KV 1000 Brushless Motor” which satisfies all the requirements. [5]

Fig. 11 Motor

- Specifications of the motor:
  - Power – 255W
  - Weight – 60g

2) Battery

Birds use their body fat to store energy for flight. In our ornithopter, the battery is the most massive component by weight and size, so it’s critical to choose the right one. To power the motor, we use a Li-Po battery. The capacity of the mass coefficient of such a cell is high. Also, they can output a high current value which is so required for brushless motors [5].

- Specifications of the battery:
  - Capacity – 1000mAh
  - 3 cells, 11.1V
  - Weight – 85g

Fig. 12 Battery

3) Electronic Speed Control

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We need a controller to control and regulate the speed of the brushless motor any hobby ESC is suitable the only thing to check is continuous and peak current. To reduce the weight of the ornithopter, it is better to choose the controller in the mini form.

- Specifications of the ESC:
    - Peak current – 20Amp
    - Weight – 20g

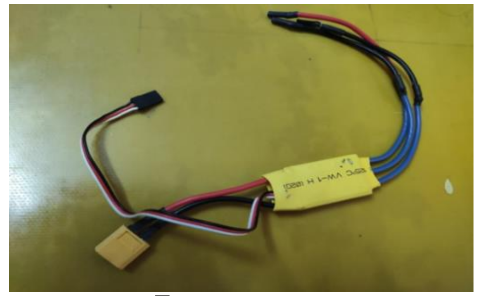

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Fig. 13 ESC

4) Servomotors

In the ornithopter, the motor is used only for flapping wings. To steer the ornithopter, we need 2 servos that will position the tail. One servo for attitude control (pitch). Second for turns (roll). This servo should be light and sturdy.

For the given purpose, the servo motor weighing 9 grams having plastic gears is selected.

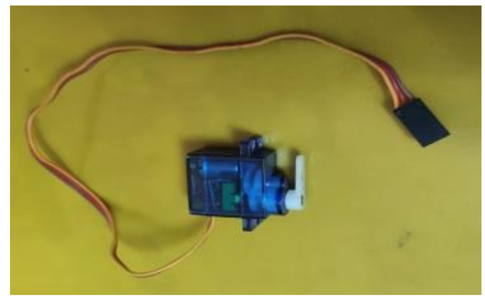

Fig. 14 Servomotor

5) R/C Controller and Receiver

The Remote Controller used to transmit commands to ornithopter was a FLYSKY FS-i6s along with FLYSKY FS-iA6B receiver. This combination was initially chosen because it offers superior protection against interface while maintaining lower power consumption and high reliable receiver sensitivity. The controller has a fairly standard set of two joysticks, each with two degrees of freedom, two dials, and four switches. It has six signal channels, mapped by default to all four joystick directions and the two dials, although this was adjusted to include one of the switches. These channels send information via pulse-width modulated signals which could control a servo or motor directly. The receiver counterpart to the controller is very lightweight, 6 channels PPM type compatible for mounting GPS and Go-pro.

Fig. 15 R/C Controller and receiver

E. Mainframe

The mainframe of the ornithopter is a surprisingly simple component from a design standpoint. Because the flapping mechanism is contained fully within the gearbox frame the mainframe of the machine serves mainly to provide mounting locations for the wing mounts, electronic components, battery, and tail assembly. The frame design is a single flat plate which relies on its thickness for stiffness.

- Material selection for mainframe
    - Mainframe – Reinforced Glass Fiber

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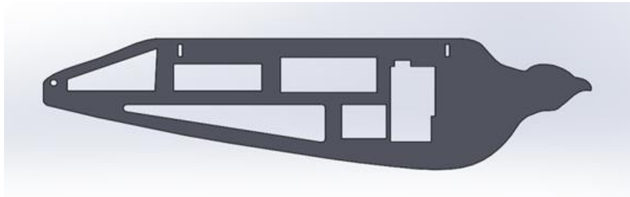

Fig. 16 Designed mainframe

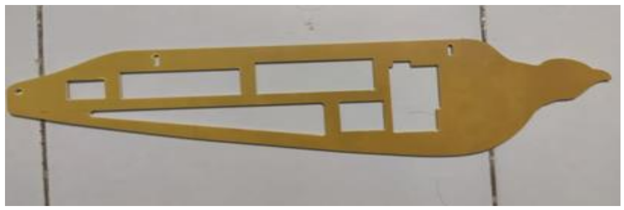

Fig. 17 Manufactured mainframe

III. ELECTRICAL SCHEMATIC

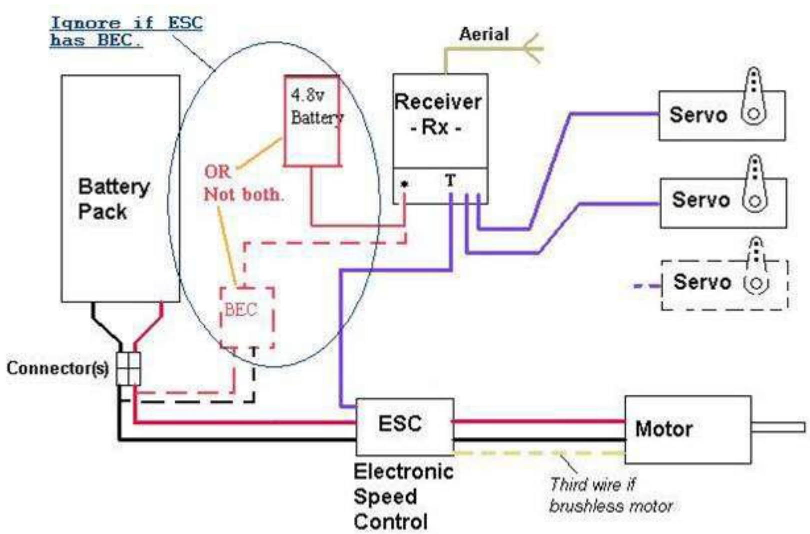

Fig. 18 Electrical Schematic

IV. CONCLUSION

The ornithopter can be designed from ground up with the needs of research in mind. All components can be designed to be as lightweight and high performance as possible to maximize payload capacity and are intended to fail in predictable and field repairable ways. In addition to this, all parts of ornithopter are simple and inexpensive to fabricate and assemble. With the newer innovations and researches in technology, we can make them as per requirements.

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In this paper, various mechanical aspects that define the designing of ornithopter has studied. The study is mainly focused on a wing and gearbox design. Other things like motor, battery, ESC, servo motors, controller and receiver are just part of selection based on payload capacity and compatibility with mechanical components.

While designing an ornithopter chronological sequence should be maintained in that according to predicted weight, flapping frequency of wing should be decided. Depending on the availability of the motor gearbox should be designed for the required reduction ratio. By doing various calculations, based on lift and drag forces, the required wing area should be calculated and from aspect ratio, length and width were decided.

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REFERENCES

[1] Seongyoung Kim, Myungkang Kim1y, Seungkeun Kimz And Jinyoung Suk1x, *Design, Fabrication and Flight Test of Articulated Ornithopter*, 10th International Micro-Air Vehicle Conference 22nd-23rd November 2018.

[2] V B Bhandari, *Machine Design Data Book*, 2nd Edition, Published: April 22, 2019.

[3] https://www.sciencelearn.org.nz/resources/302-wing-aspect-ratio

[4] Dan Sanderson, Jourdan McKenna, Brian Baggaley, and Frederick Wight, *Design and Implementation of an Ornithopter*, Worcester Polytechnic Institute April 28, 2016.

[5] https://www.ornithopter.org/how.motor.shtml

[6] https://www.ornithopter.org/how.stab.shtml

[7] Sushobhan Guha, Yash Tanna, Mehak Kar, and Prof. Amisha Pathak, *Ornithopter with Articulated Wings*, IJSTE - International Journal of Science Technology & Engineering | Volume 3 | Issue 10 | April 2017

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