

Designing a Radio Frequency Controlled Biomimetic Flying Bird

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APPROVAL

The thesis report “Designing a Radio Frequency Controlled Biomimetic Flying Bird” submitted by Nahid Hasan Adnan and Mohammad TalhaTalkinAlam to the Department of Electrical and Electronics Engineering, BRAC University Bangladesh, has been accepted as satisfactory for the partial fulfillment of the requirements for the degree of Bachelor of Science (Hons.) in Electrical and Electronics Engineering and approved as to its style and contents.

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DECLARATION

We, hereby, declare that the thesis titled ““Designing a Radio Frequency Controlled Biomimetic Flying Bird” is submitted to the Department of Electrical and Electronic Engineering of BRAC University in partial fulfillment of the requirements for the degree of Bachelor of Science in Electrical and Electronic Engineering. This is our genuine work and has not submitted elsewhere for the award of any other degree or diploma.

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List of Abbreviations

UAV = Unmanned Aerial vehicle

MAV = Micro Aerial Vehicle

CIA = Central Intelligence Agency

DARPA = Defense Advanced Research Projects Agency

NAV = Nano Air Vehicle

CF Rods = Carbon Fiber Rods

ESC = Electronic Speed Control

FHSS = Frequency-hopping Spread Spectrum

DHSS = Direct-hopping *Spread Spectrum*

DSSS = Direct Sequence Spread Spectrum

AM = Amplitude Modulation

FM = Frequency Modulation

RX = Radio signal receiver module

FPV = First Person View

List of Variables

V = Air speed

S = Area of the wing

F_L = Lift force

ρ = Density of air

C_L = Lift co-efficient

M = Bird's mass

g = Gravitational acceleration

R_g = Glide ratio

A_0 = Wing flapping amplitude

f = Wing flapping frequency

β = Angle of attack

Table of contents

CHAPTERS	Page No.
Abstract-----	01
Chapter-1: Introduction	
1.1 Introduction-----	02
1.2 Unmanned Ornithopters-----	03
1.3 Literature Review-----	10
1.4 Thesis Objective-----	11
Chapter-2: Model Description	
2.1 Forces-----	12
2.2 Wing Geometry and Construction-----	17
2.3 Gearbox-----	22
2.4 Power Source-----	26
2.4.1 Motor-----	26
2.4.2 Battery-----	28
2.5 Tail Design-----	29
2.6 Communication-----	30
2.7 Main Frame-----	32
Chapter-3: Conclusion	
3.1 An outline of future work-----	34
3.2 Conclusion -----	36
4. References-----	37

List of Figures

FIGURES	Page No.
FIGURE 1.1 Insectothopter robotic CIA dragonfly-----	4
FIGURE 1.2: Nathan Chronister's hovering ornithopter. The right one is 2007 version	4
FIGURE 1.3: The Microbat-----	5
FIGURE 1.4: Delfly-----	5
FIGURE 1.5: Peter Muren's micro ornithopter-----	6
FIGURE 1.6: Aerovironment's Nano Hummingbird-----	7
FIGURE 1.7: Sean Kinkade's Skybird-----	7
FIGURE 1.8: Robert Muster's RC ornithopter used to bird control in airports-----	8
FIGURE 1.9: Nanda Kumar's Ornithopter-----	8
FIGURE 1.10: Yusuke Takahashi's ornithopter-----	9
FIGURE 1.11: Festo Smart Bird-----	9
FIGURE 2.1: Four main forces acting on a bird-----	13
FIGURE 2.2: Lift generation technique of a typical airfoil-----	14

FIGURE 2.3: Wing's angle of attack contributes in lift generation-----	15
FIGURE 2.4: Wing shapes template for cutting the polyethylene films in shape, shaped wing films, 3mm fiberglass rods, thin bamboo slices and area calculation technique are used in the wing construction-----	21
FIGURE 2.5: A semi span image of wings-----	22
FIGURE 2.6: A hand drawing of the gearbox plan (2D view)-----	23
FIGURE 2.7: Micro ball bearings and 3mm steel rods are used in gearbox construction-----	24
FIGURE 2.8: Crank-Shaft mechanism-----	25
FIGURE 2.9: 52 teeth final drive gear and 11 teeth parallel gear with 48 teeth spur gear-----	25
FIGURE 2.10: Upside down view of the gearbox-----	26
FIGURE 2.11: A Turnigy L2205 1350KV(rpm/v) Brushless Outrunner DC motor. The outer magnet can rotate and the coil remains stationary-----	27
FIGURE 2.12: Brushless electronic speed controllers and Li-Po batteries. A 18A Brushless ESC and a 3S 1100mAh Li-po have been used as the power source-----	28
FIGURE 2.13: Top view of tail (left image) and inside view of tail (right image)-----	29
FIGURE 2.14: Tail combinations-----	30
FIGURE 2.15: Turnigy 2.4GHz Transmitter (left) and receiver (right)-----	31
FIGURE 2.16: The image of the model-----	33
FIGURE 3.1: GLDAB gliding device and mechanism-----	34
FIGURE 3.2: Soaring of a bird-----	35

Abstract

The present world has been reached to a stage where most of the sophisticated and sensitive tasks are mostly done by artificial hands. Drones, robots have been replaced the place of human with their uncompromised accuracy and efficiencies. Regards this phenomenon the importance of study about robots or unmanned vehicles to perform sensitive works under human supervision is a high demand of time. We are concentrating on the aerial vehicles; want to integrate our ideas and works to develop a new type of flight system to improve the control and maneuvering abilities of flying UAVs or drones. Our experiments can open a port for next generation flight development for drone applications. Our logic is nothing can fly efficient as the birds do. So copying from the flying behavior of it is possible to gain all the abilities like the bird. We developed a model which flaps its wings in fixed amplitude with variable frequencies. To do this we introduced a crank shaft mechanism to drive the wings. The model is powered by a 100watt dc motor with necessary gearbox assemblies. Making it light weight was always a big challenge from the beginning. With this race we avoided unnecessary decorations in this primary level. The controlling and maneuvering has been done by a radio communication and bird like tail consequently. 3channel radio communication is needed to control the flapping frequency and tail combinations. Flying upward, downward, left, right and 360 degree rolling is possible with this tail combination. We used micro servo motors for tail mechanism. The detailed way the model has been built and the design limitation is illustrated in this thesis.

CHAPTER 1- Introduction

1.1 Introduction

Inspired with the present development in flapping UAV(Unmanned aerial vehicle) research, we wanted to join the theories on how a biomimetic vehicle can be constructed that can perform a sustained flight and have the controllability in parallel. These types of vehicles are mostly known as ornithopters. Ornithopter came from the Greek word “ornithos” means “bird” and “pteron” means “wing”. It is an aircraft that flies by flapping its wings. The first ornithopter was constructed in France by Jobert in 1871 and was rubber band powered [1]. Though in case of efficiency, modern aircraft design is the best for steady flight but it sacrifices maneuverability on the hidden part. Biomimetic flapping vehicle’s flight is mostly unsteady but comes up with a higher resolution of maneuverability, what we can see in birds or insects. Within a few area it can fly upward and downward, can perform vertical flight and can soar. At present we have fixed wing and rotor wing vehicles those are not capable with all these capabilities all along. For cruise flight airplane is best. For vertical take-off we built choppers. But birds fly in combination with a motion of vertical flap, a horizontal motion and a torsion motion [2]. Although the exact modeling of flapping flight couldn’t be developed for its complexity but researchers were partially able to find the codes on how bird manage its horizontal and vertical required forces to fly in steady state. We are saying it partially able because biologists stand against mathematical modeling of birds [3]. It was observed that in low Reynold’s number it is efficient to build a vehicle like an insect shaped with their characteristic flight [4]. But there are many difficulties in building an efficient flapping mechanism and fabrication of biomimetic wings due to the limitations and materials. We have chosen our vehicle in middle of the large bird and the insect to better study and avoid the complexity to building procedure as much as possible. Our study mostly covers the flight characteristics of flapping birds. All theories and design ideas are found from online journals, research papers and hobbyists’ sharing. Though the theories could not give the real calculations in most of the cases as we read from the resources, we roughly followed the formulas and design techniques to get closer in our work. We first considered building the model from our earned ideas and then analyzed the test results with the theory. We want to use our model to build future smart ornithopters with cameras and GPS technologies those will be used

for military applications such as aerial reconnaissance without alerting the enemies that they are under surveillance. We hope further improvements with AI capabilities will give the ornithopter a higher level of respect.

1.2 Unmanned Ornithopters:

The first unmanned ornithopter was powered by rubber band. Jobert was the first to create one of these types in 1871. It was powered by a stretched rubber band turning a crank. In the following year, Jobert built a biplane (four-winged) ornithopter with the twisted rubber band motor more common today. The use of four wings was a clever innovation that reduced the amount of torque needed to flap the wings[5]. After that many people actually implemented the rubber band technique with different crank mechanism. There are many links from where the information can be found about those works. But most of them were not well recorded and it is hard to find those studies and specifications. Nathan Chronister writes in his ornithopter zone [6] about those records. He was spending decades to discover about the history of ornithopters and tried to verify all of those records personally by contacting with people. So to search for the historical background of ornithopters we go through his ornithopter zone and collected most information from there. Rest of the works was found from numerous video uploads and online research papers and books. To describe about all models is out of our scope in this paper. Three types of models were found as far about ornithopters. They are internal combustion powered, rubber band powered and electric powered. The crank mechanism can also play role to separate models from each other. The hobbyists today's use rubber band and electric dc motors to build their designs. As with the technological improvement there is wide variety of dc motors and other accessories. In case of MAV research we found some examples of flapping wing vehicles. There is some other hobbyist's model which earned a lot of public interest and had a wise engineering. We will present here some models from these areas to keep our paper simple and more concentrated to our work.

In 1970 USA CIA used a tiny 1g weight dragonfly looking ornithopter that was able to fly for 60seconds using gas producing chemicals. It had a 9cm wingspan and was controlled with some kind of laser guidance system which was not that much effective. A laser beam steered the dragonfly and a watchmaker on the project crafted a miniature oscillating engine so the wings beat, and the fuel bladder carried liquid propellant. SF writer Raymond Z. Gallun thought about

this sort of device as a kind of insectile spy about 75 years ago. In his 1936 story *The Scarab*, he wrote at length about a robotic beetle that could be used as a surveillance device. The Project team lost control over the dragonfly in even a gentle wind [7]. The so-called “Insectothopter” never got the chance to fly under the radar after test missions showed that it was easily compromised by gusts of wind and just plain difficult to control [8].



FIGURE 1.1: Insectothopter robotic CIA dragonfly

In 1997, Nathan Chronister built a four-winged ornithopter that could hover and perform aerobatic maneuvers using a vertical wing stroke. This is similar to dragonflies. In 2007 he built another model. Though it was developed for recreational use but achieved a MAV benchmark as it had the similar size and weight of a hummingbird. It had a 3.3g weight and 15cm wingspan [5].

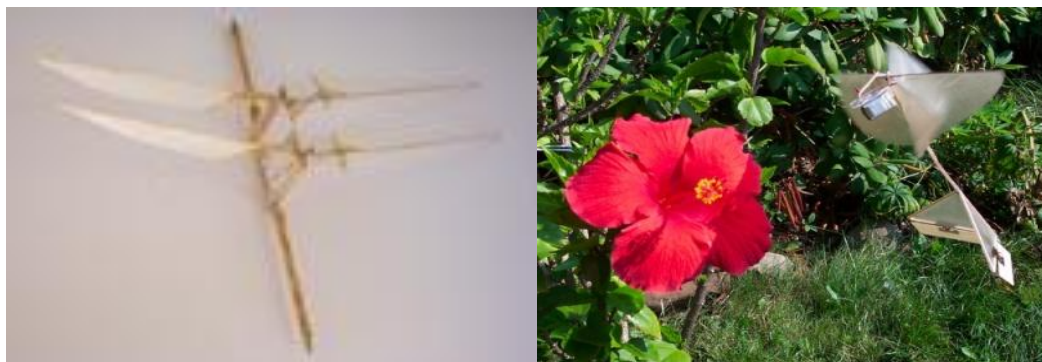


FIGURE 1.2: Nathan Chronister's hovering ornithopter. The right one is 2007 version

In 2000, The MicroBat was developed by Aerovironment and Caltech. It was the first micro-sized ornithopter resulting from MAV funding. It had three-channel radio control and used one of the lithium-polymer batteries which had just become available [2].



FIGURE 1.3: The Microbat

Delfly was developed at the Technical University of Delft and Wageningen University, is able to transition between hovering and forward flight. These ornithopters also carry a small video camera as payload. The live images are analyzed by a computer on the ground, giving Delfly the capacity for autonomous navigation. (The newest version as of 2013 has an onboard visual navigation system). The year was 2006 [2].



FIGURE 1.4: Delfly

The world's smallest radio-controlled ornithopter is PetterMuren's and has a wingspan of 10 cm and weighs only 1 gram. It was built in the year 2007.



FIGURE 1.5: Peter Muren's micro ornithopter

Aerovironment's Nano Hummingbird, while not especially small, was a huge breakthrough in MAV ornithopter research because of its gyroscopically stabilized flight without any tail surfaces. The Hummingbird is equipped with a small video camera for surveillance and reconnaissance purposes and, for now, operates in the air for up to 11 minutes. It can fly outdoors, or enter a doorway to investigate indoor environments. It was announced to the public on 17 February 2011. DARPA contributed \$4 million to Aero Vironment since 2006 to create a prototype "hummingbird-like" aircraft for the Nano Air Vehicle (NAV) program. The result was called the Nano Hummingbird which can fly at 11 miles per hour (18 km/h) and move in three axes of motion. The aircraft can climb and descend vertically; fly sideways left and right; forward and backward; rotate clockwise and counter-clockwise; and hover in mid-air. The artificial hummingbird maneuvers using its flapping wings for propulsion and attitude control. It has a body shaped like a real hummingbird, a wingspan of 6.3 inches (160 mm), and a total flying weight of 0.67 ounces (19 g)—less than an AA battery. This includes the systems required for flight: batteries, motors, and communications systems; as well as the video camera payload. [6]

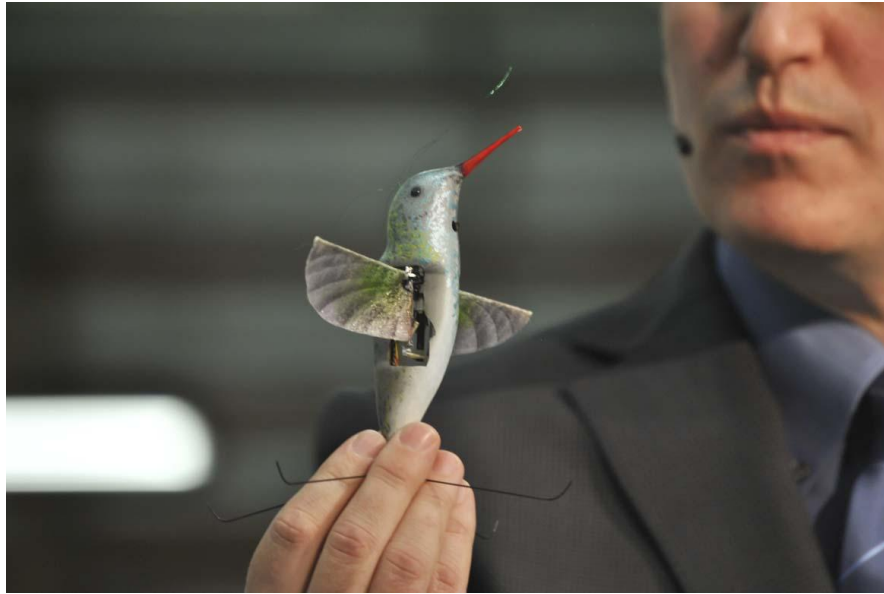


FIG 1.6: Aerovironment's Nano Hummingbird

Sean Kinkadee's Skybird (1998), based somewhat on the Spencer Seagulls and using a 0.15 methanol-fueled engine, was an attempt at small-scale commercial production of an RC ornithopter. Smaller, electric versions were later offered [2].



FIGURE 1.7: Sean Kinkadee's Skybird

Robert Musters began a series of RC ornithopters in 2007 with foam, actively twisted wings. The appearance of these ornithopters is close to that of a real bird and they are being offered for use in bird control at airports.



FIGURE 1.8: Robert Muster's RC ornithopter used to bird control in airports

A flying machine built by Mr. Nanda Kumar won him limca world record and lot of credits. This is a metal bird that can fly by flapping its wings. It is heights of accuracy. It is remote controlled to fly up/down and right/left. He currently holds his record for India's First Ornithopter.[7]



FIGURE 1.9: Nanda Kumar's Ornithopter

In 2005, Yusuke Takahashi converted the Luna to remote control, and discovered that with the addition of an elevator control function, the already slow-flying design could be made to hover. The Luna ornithopter model kit introduced a simple scissor-wing design, which simplified construction and led to a proliferation of four-winged ornithopters. Takahashi has built many other micro-sized RC ornithopters with very creative designs. [2]



FIGURE 1.10: Yusuke Takahashi's ornithopter

Smart Bird is an ultralight but powerful flight model with excellent aerodynamic qualities and extreme agility. With SmartBird, Festo has succeeded in deciphering the flight of birds – one of the oldest dreams of humankind. Smartbird is constructed of polyurethane foam and carbon fiber and is powered by a 135 brushless motor running at 23 watts. [8]



FIGURE 1.11: Festo Smart Bird

1.3 Literature Review

From the analysis of early works up to these writing shows up MAV requires micro sized vehicles whether we want our model to be much bigger than that. We are focusing on UAV development before we modify our model for MAV. A bigger model is easier to handle and also finds out problems on miniaturization of a given model. We observed some models of ornithopters that were build mainly by hobbyists where the main goal was to prepare their bird for a sustained flight and efficient controlling. Copying from bird's flight theories is not that much easier what was done by the peoples from aeronautics and hobbyists. They use a very limited knowledge on their attempt. Birds use dynamic flying techniques but all possible models till now has some major limitations like fixed amplitude flapping with variable frequency, no wing twisting mechanism, absence of upstroke negative lift elimination technique, unable of versatile maneuvering, dependency on take-off and successful landing. However, we gathered some studies on mechanical birds and autonomous control techniques for them which were valid for their cruise flight or hovering flight. A work on smaller ornithopter was published by JoonHyuk Park, Kwang-Joon Yoon from the Department of Aerospace Information System and Artificial Muscle Research Center in Konkuk University, Korea. Their demonstration was on scratch building of small sized ornithopter. The way to build and flapping mechanism was described there. [4] Among all the bigger models, the ornithopter from Sean Kinkade named Park Hawk has an efficient control including gliding capabilities and higher altitude flying. But Kinkade's model holds a patent on the design and he turned his work into his business. Kinkade is the designer of much wide range of radio-controlled ornithopters both smaller and larger. After his death in February 2013 all his plans went with him. Park Hawk is no longer available now. A research on making a Park Hawk autonomous was done by Zachary John Jackowski. From his paper some important informations were found from Kinkades works and choices on following a bird's flight. [13] There are also other famous designers like Kazuhiko Kakuta, Nathan Chronister. Other plans were exceedingly hard to obtain. Very little works has published still now. Ornithopters design in similar form factor that focus on additional degrees of freedom to the wings have been published [14] in addition to a variable amplitude wing design produced by robot locomotion group previously. An extensive analysis of the wing design has been performed with a motion capture system by Robyn Harmon of the Morpheus Lab at the University of Maryland which explains many of the aerodynamic properties of this type of ornithopter. [15]

James Delaurier's work forms much of what has been accomplished in larger scale ornithopter design and analysis. [16]

1.4 Thesis Objective

Our objective is to bring the visual appearance and characteristic flying of a bird into a radio controlled flying vehicle. We want to develop an UAV of this type as because it will be harder to detect rather than normal fixed wing or rotor winged UAVs from the ground and can be used as surveillance monitoring. It can be designed to achieve a good level maneuverability than any other flying UAVs of same size. This is good to work with a larger model before we start developing it for MAV applications. We have chosen a larger model and tried for a simplified flying mechanism at first. Bird's flying is very complex and driving the wings like a bird is still in under experimental level. That's why the efficiency of this type might not be that much. Wing designing and changing the mechanism of flapping or controlling can greatly improve it. Our purpose is, knowing the techniques of real bird's flying and taking from that as much as possible. Making it flying is not the only goal but flying like the bird is the major goal of this thesis. After the successful implementation of all the logics of natural flight we want our model will be turned into a special purpose UAV with many facilities. In future it will help to miniature the model for MAV development.

CHAPTER2-Model Description

2.1 Forces

A flapping UAV is a flight vehicle which generates aerodynamic forces and moments to fly. The flexibility of wings contributes to gaining sufficient lift and thrust. Even for the design of small flapping UAV, there are too many design parameters including wing geometry, wing kinematics, and wing structural dynamics. It is not yet clear of each parameter's effects in the total aerodynamics of a model. Commercially available toy flappers can barely fly, and it is difficult for them to carry additional payloads, such as cameras and chemical sensors. Giving them a payload instantly changes their behavior. From a research paper [17], we found that when it was installed additional mass (5% of the entire system mass) onto a toy flapper at the center of gravity so that the flapper's longitudinal dynamics were changed as little as possible. Then, with the wing area was gradually increased until the modified flappers could fly.

However, those modified flappers proved ineffective; if the wing area was enlarged, much higher torque and power were required. Moreover, the wing is not rigid, so structural properties such as mode shapes and natural frequencies should be tuned for an enlarged wing. This made them replacing motor, transmissions, and the discharge rate of the battery to match the flapping frequency, which increased the system weight. So we went through the general bird flight physics to build the base of our model. We began with the main fundamental forces those are need to be balanced must for the flight. Four force acts directly on a flying model. These are lift force, drag force, thrust force and weight of the bird. Thrust and drag cancels each other and same thing goes for lift and weight when the model is in cruising flight.

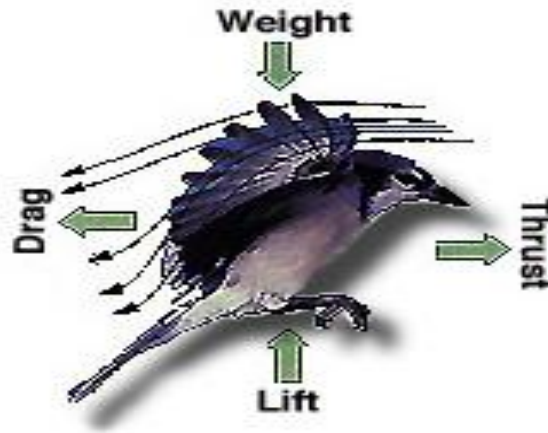


FIGURE 2.1: Four main forces acting on a bird

Lift is the function of the air density, the square of the velocity, the air's viscosity and compressibility, the surface area over which the air flows, the body shape, and the wing angle to the flow. Importantly the lift must be equal of more than the total weight of the bird. Efficient lift generation mostly depends on the wing design. Wing is responsible for the maneuverability of the system. It's aspect ratio, angle of attack, wing loading all these terms are related to gain the efficiency in flight. The cross section of a bird's wing is known as "airfoil shaped" and the airfoil shape mainly describes how lift force is generated. From bird's wing we found that the wings are shaped in such a way that the distance from the front to back over the top of the wing is greater than the distance measured under the wing. That means the wing is curved in width at an angle inside of it. But through the length, it is straight when the wing is stretched in the air. This curvature is the main formula of the lift generation, which was found from "Bernoulli's theorem". In order for the same amount of air to pass over the longer distance on top, the air flows much faster over the top and slower over the bottom as the distance is lower there. To avoid the mathematical complexity of the velocity distribution and pressure distributions on the airfoil surface because of the airflow, we are simply saying that the airfoil gains a large lift force for an inclination angle below the critical angle of attack.

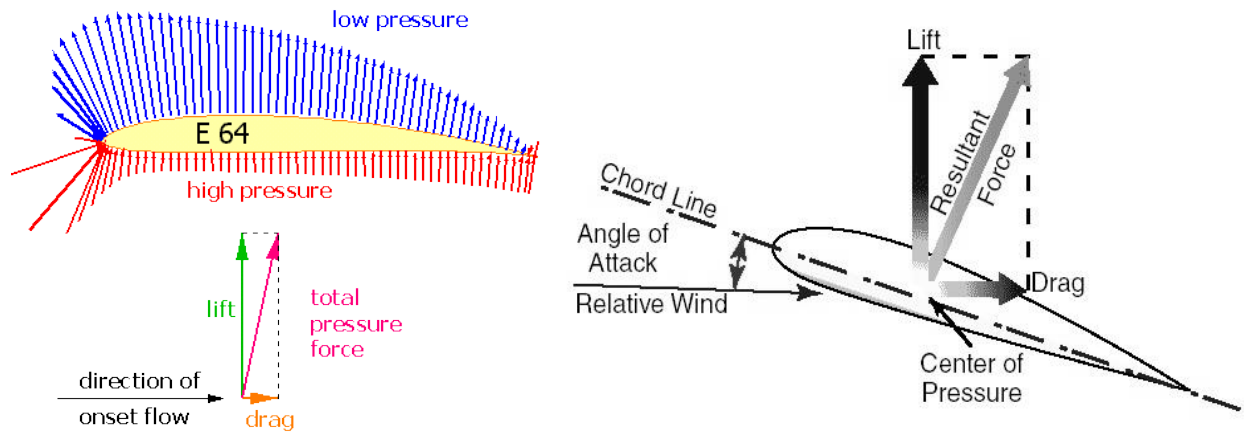


FIGURE 2.2: Lift generation technique of a typical airfoil

Not only airfoil is important to generate sufficient lift force to fly a bird but also there are some variables that are responsible. These are wing size, airspeed, air density, or angle of attack of the airfoil. To get the general equation of the light, we need to take care about some basic relationship. The relation between wing size (we call it wing surfaces) and lift L is

$$\text{Lift} \propto \text{Wing surface area}$$

The relationship between lift and airspeed is less straight forward. We need to find first the amount of airflow around the wing first. The mass flow of air around the wing first. The mass flow of air around a wing is proportional to the airspeed V times the air density d . Now using Newton's 2nd law of motion, we can find the force caused by airflow and that is $V \cdot d \cdot V$ or dV^2 . Since bird's wings has to support its weight against the gravitational force lift must be equal the weight W . So the final relationship becomes,

$$W = 0.3dV^2S$$

Here 0.3 is the constant related to the angle of attack for cruise flight. Its average value is 6° . If we modify the equation like below,

$$W/S = 0.3dV^2$$

We find the wing loading. Here W/S is the wing loading from which we can understand that higher the wing loading, faster the bird must fly to overcome its weight force (gravity). That is

why, a Boeing 747 flying with a higher wing loading and take-off speed is much higher in order to generate take-off lift force.

When a wing moves through still air, the air exerts a force to the wing. If the wing is parallel with the air threads then the force is entirely a drag force. But if an inclination angle is kept (above 0° to 15°), we can get a lift force from the wing. This phenomenon can be described wing the following diagram.

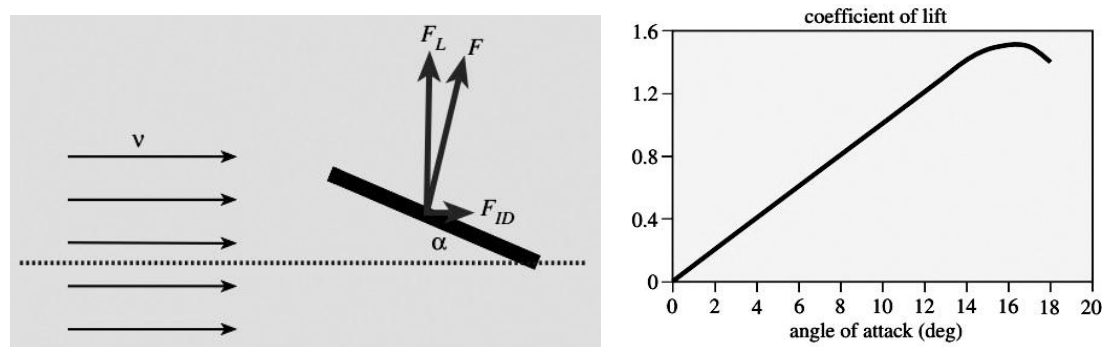


FIGURE 2.3: Wing's angle of attack contributes in lift generation

For an angle of attack that is greater than 0° and less than 15° , we get a lift force component F_L at the right angle of the air a lift force component F_L at the right angle of the air flow lines. For efficient wing design, the angle is not exactly the right angle, but it is inclined forwards with respect to the wing chord. At higher angles of attack, air flow over the top of the wing detaches and the wing stalls. The forward component of lift is important to produce a thrust component for the bird. At a given angle there will be so much lift and so much drag. By dividing the lift by the drag, the lift to drag ratio is obtained. As lift and drag change with angle, the lift to drag ratio will also change. There will be an angle at which the lift to drag ratio is largest, where we will get the greatest lift, for the least amount of drag. It is essential to make the wing operate at this angle throughout most of the stroke. By doing it we can guarantee that for the amount of drag being counteracted, we are getting the greatest lift possible.

J. Oliver Linton used the formula of lift force F_L in his paper is

$$F_L = \frac{1}{2} C_L \cdot S \cdot \rho \cdot V^2$$

Where,

S =Area of the wing

ρ =Density of air

V =velocity of wing

C_L =Lift co-efficient and critically varies with angle of attack

And

$$C_L \approx k_L \alpha$$

k_L is approximately equal to 5 and α measured in radians.

Finally, the mean lift force from his became,

$$\text{Mean Lift} = \frac{1}{4} k_L \beta S \rho V^2$$

As J Oliver described that bird wings don't contribute neither on lift nor thrust during the upstroke.

Note: β represents angle of attack, S is the wing area, ρ is density of air and V is the wing speed through the air. The standard value of air density was taken 1.3 kg/m^3 . The equation of β in term of bird's mass is

$$\beta = \frac{4Mg}{k_L S \rho V^2}$$

Here M is the bird's mass; g stands for gravitational acceleration and R_g is the glide ratio.

The formula of thrust generation is,

$$\text{Mean thrust} = \frac{1}{6} k_L S \rho \sigma^2 V^2$$

Here, σ = Strouhal Number. For cruising flight value is 0.2.

The power equation is simply (thrust*speed). Therefore,

$$\text{Power} = \frac{1}{6} k_L S \rho \sigma^2 V^3$$

Note: A_0 = wing flapping amplitude, f = wing flapping frequency; Rest of the variables hold their previous meanings.

However, it's our best interest to achieve as much static thrust as possible. For the ornithopter to fly vertically indefinitely, we need to produce more thrust than it weights. The thrust must counteract the weight of the ornithopter and whatever thrust is left counteracts the drag while it's moving vertically. To achieve this we need to make the wings move as quickly as possible with the least resistance possible. The more resistance there is, the more the motor slows down in our model and the less lift the wings produce. This is done by making the angle the wing sweeps across as large as can be. This increases the speed of the wing while minimizing its acceleration. The force required to accelerate a wing to an oscillation increases with the square of the frequency and it changes linearly with amplitude. Lift on the other hand increases with the square of the speed, and the speed increases linearly with both frequency and amplitude. This means that by doubling the frequency, the lift quadruples, yet the force required to accelerate it also quadruples. If we double the amplitude, the velocity will double, and as such the lift will quadruple, yet the force required accelerating only doubles. This means that we can achieve the same lift for half the resistance by increasing amplitude instead of frequency.

2.2 Wing Geometry and Construction

Wings are the most important parts of our model which can determine the flight characteristics of the ornithopter. Aspect ratio and wing loading should come here under careful considerations. Wing aspect ratio can tell the maneuverability of any bird. It is simply wing length over wing width (chord). We will consider here the average wing chord value as the wing shape is irregular. Generally, high aspect ratio wings give slightly more lift and enable sustained, endurance flight,

while low aspect ratio wings are best for swift maneuverability. It is wise to go for a high aspect ratio wing for the ornithopter as it will deliver a better gliding performance. High aspect ratio wings need to be fed with strong wing hinges and therefore other arrangements should be sufficiently stronger to support the wing movement. It also demands more power from the power system and the wing design should be intelligent enough to reduce its weight and area that best suits the whole system. High aspect ratio wings have some following characteristics.

Stability: Long narrow wings give more stability. The trade-off is that this type of ornithopter won't be very maneuverable.

Less induced drag: Long, narrow wings also have less induced drag than shorter wider wings. Induced drag is created at the tips of the wings where the high pressure air from beneath the wing comes up over the wing tips into the low pressure zone. This meeting place of different air pressures becomes a turbulent area creating induced drag. Long narrow wings have less end edges (tips) and more stable wing area than shorter wider wings so they have less drag.

Less fuel consumption: Having less induced drag means there is less fuel consumption for planes and birds (fat consumption) so they can keep their speed for a longer time than short wide-winged fliers.

Other vital consideration about wing construction is wing loading. Wing load factor is the ratio of the total load supported by the wing to the total weight of the system. In still air flight, the load on the wing equals the lift it generates. The load factor is expressed in G units. In an unaccelerated level flight the load on the wings is equal to lift and to the weight. Consequently, the load factor equals 1G. If $\text{Lift} = \text{Weight}$ then $\text{Lift} / \text{Weight} = 1\text{G}$. The load factor may be positive or negative. During normal flight, the load factor is 1 G or greater than 1 G. whenever the load factor is one or greater the load factor is defined as positive. Under certain conditions, an abrupt deviation from the system's equilibrium can cause an inertial acceleration that in turn will cause the weight to become greater than the lift. For example, during a stall, the load factor may be reduced towards zero. A sudden and forceful elevator control movement forward can cause the load factor to move into a negative region. Both excessive deviations from positive and negative load factor limits must be avoided because of the possibility of exceeding the structural load limits of the ornithopter. Keeping all these in mind we have chosen a wing

span of 90cm for our model and tried to keep the area sufficiently bigger as because we are not getting the information whether the flight speed of our model will be enough to generate minimum lift force to overcome the weight without experimental results. Lift increases with wing area and speed. So if we were sure about much thrust generation with our wing then, we could compensate our wing area to reduce power consumption and wing momentum. Shape of the wing is elliptical and the wing has an area of 1263cm^2 . Average chord length is 11.92cm^2 . Wing aspect ratio and wing loading was 6.7 and 0.38 g/cm^2 consecutively.

We found the birds which have a matching weight with our design flap their wings three to six times per second. A paper from Pennychuick recorded all these data from field experiments in various conditions of bird flight [18]. There are two spars, one at the leading edge and another placed diagonally from the leading edge to the rear of the fuselage. This spar arrangement creates two regions in the wing, the triangular “luff” region, which is a loose membrane, and the “flap” region which is kept taught by a series of fingers that run from the diagonal spar to the trailing edge. The flexible skeleton-membrane structure allows for highly dynamic passive shape change as the wing moves through the air. The large degree of bending in the wing is a result of the membrane adjusting its camber and pitch to maintain tension equilibrium throughout its surface. At the beginning of down-stroke and upstroke the inertial acceleration of the wing causes the leading edge spar to bend significantly. This results in a variation of the local stroke angle along the span and therefore a phase-lag between the wing root and wing tip during the stroke period. Additionally, since the flap region is essentially hinged about the diagonal spar, it experiences a large deflection. A consequence of the flap deflection is that the flap’s force loading exerts a moment on the wing that increases the pitch into the flapping motion, so if the wing is in down-stroke, it will have downward or negative pitch. This pitch adjustment is important to maintain a relative angle of attack with minimal stall, whereas an untwisted rigid wing would experience accelerated flow separation due to the large inflow angles. The wings have a triangular support structure. A main spar runs along the leading edge of the wing and a strut connects from the rear of the ornithopter's body to a point near the tip of the main spar. From this strut there are several smaller carbon rods that project to the edge of the wing which are somewhat free to move. This result in a fanning motion from the trailing edge of the wing that produces a component of thrust while the leading edge is flapping up and down which directly contributes to a part of the lift in addition to the conventional lift coming from airflow over the wing. Flexible diagonal bracing

was introduced by Percival Spencer. The torsion flexing of the wing can be controlled by adding a diagonal brace. However, the brace must be flexible enough to conform to the conic shape that the wing should have under load. If the bracing rods are too stiff, they will cause a discontinuity in the cambered cross-section of the wing, making the airfoil less efficient. Sometimes a more rigid brace is used, but it should be confined to a small portion of the wing. To give our system a better stability and because of other structural limitations we have limited our upstroke and down stroke angle in such way that it has an average dihedral angle of 5° . We kept upstroke angle 35° that bigger than the down stroke angle of 25° . So the total flapping amplitude becomes 60° and 5 degree stroke angle difference gives 5 degree average dihedral angle. In the context of aircraft flight, the dihedral effect is the phenomenon of roll moment created from sideslip. The dihedral effect of an aircraft is largely affected by its dihedral angle, which is the angle of deflection of the wings from level in the roll plane. Positive values indicate the wing tips are above the wing roots (the wings go up as they get farther from the plane), while negative values indicate the tips are below the roots (the wings go down as they get farther from the plane). When the aircraft rolls, this effect will tend to either create a restoring moment or a deviating moment, respectively. In other words, a positive dihedral angle tends to increase stability, while a negative dihedral angle tends to increase maneuverability. These both have their applications, as stability is desirable for passenger and cargo planes and the like, while maneuverability is preferable for fighter aircraft. As for flapping flight no fixed dihedral angle of wing can be obtained as it varies with time. So our goal was to go for an average and positive dihedral effect.

We have used polyethylene plastic film to build our wing. For the wing stiffeners 3mm Carbon fiber rods had to be used but we could manage 3mm glass fiber rods. Glass fiber rods cannot be a proper alternative of CF rods. CF rod is lighter and stiffer than fiberglass. The nature of a carbon fiber is very light, rigid, and strong. This is why most weight-critical performance products are being manufactured with carbon fiber. Carbon fiber is very strong and very rigid, while fiberglass is also very strong but it is not as rigid. In applications where a small amount of flexibility is desired, carbon fiber is the material of choice. In applications where a large amount of flexibility is desired, fiberglass is probably better suited. Fiberglass is better suited to extreme flex patterns, while carbon fiber has a relatively small flex window. We want have our wing bending behavior that follows the stiffness and flexible behavior of Carbon fiber rods.



FIGURE 2.5: A semi span image of wings

2.3 Gearbox

The gearbox design has a great importance in the long run. Before start building of it we need the wing specifications, weight information to choose our required flapping frequency that will be provided by the dc motor. But as motor rpm is relatively very high and torque creation is also important with it so we must gear down our motor before we plan to attach it with the wings. Otherwise it can break the wing joints or can damage the frame badly. Another problem may arise that, if the wings become too heavy for the motor it can force to stall the motor and burn it with blue flames. That is obviously not expected. We need a perfect gearbox to avoid these types of problems. Gears with perfect match with our design are like dreams. But we could reach near of it. The problem is the availability of the perfect gears in market. We had a very narrow range

of options to choice. It was seen that while we could manage the specific teeth numbers, then we faced problems with gear's pitch. It was impossible to mesh those teeth with each other. Finally we could build one that can gear down a 1350rpm/V dc motor with a 13.34:1 gear ratio. We could add more gears but this has a greater disadvantage. It will make the gearbox heavier and more tough and complex to build. Human hands are not perfect for these types of building. Making drills in perfect distance to hold the gear, x & y axis alignment, meshing the gears these are works that should be done by a computerized cutting machine. But we tried our best to make it possible with our hand works with careful geometric operations. The motor pinion has 17 teeth. 2 spur gears were used. One has 48 teeth and another has 52 teeth. A parallel 11 teeth gear was used with the 48 teeth gear to transfer the energy to the final gear.

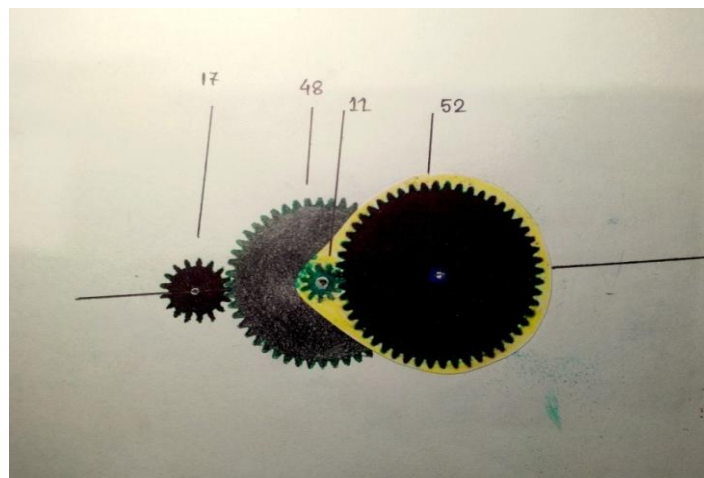


FIGURE 2.6: A hand drawing of the gearbox plan (2D view)

Our wing's desired flapping frequency is 6hz at full stick throttle. But this gives almost 18 rpm theoretically at the final drive. However from the guidance of ornithopter building forum this specification was warmly taken. The reason they described about it was in most cases there are many types of losses like frictional loss or practical rpm variations in loaded or no load situations. The final rpm is for full stick operation and we can tell this that we not going to operate the ornithopter at full stick. As we can vary the motor rpm with time we can easily limit the lift generation in a motor efficient way. This will remove extra loads from the motor. The gearbox assembling part was the most complicated side of the total building process. The spur gears have 7mm hole diameter. Our choice was to use pinion wire that will go through it. We could not

manage pinion wires so we used to fill the gap with a piece of pencil after replacing its lead with a 3mm aluminum rod. 3mm ball bearing was use on the both sides of the axel to hold the gear and give it a frictionless environment. Plywood frame was used to hold all the things with the fuselage. The motor was placed in exact position with the gearbox and we don't agree to separate the motor from the gearbox family; though we discussed about the motor in section 4.4 in details. We used strong adhesive named "Fevicol super glue" to stick the ball bearings with the plywood frame and also to join the related parts with the main frame. To help survive the gearbox in heavy jerk sufficient attention was taken to design the gearbox frame also.



FIGURE 2.7: Micro ball bearings and 3mm steel rods are used in gearbox construction

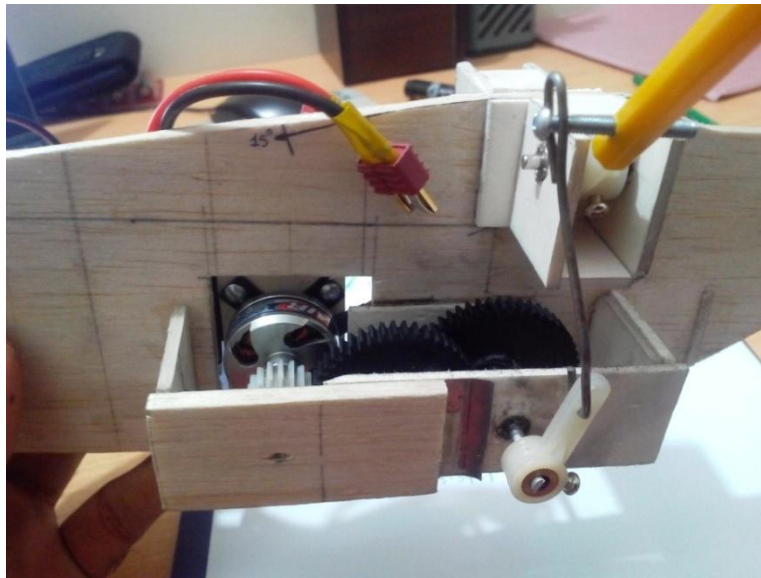


FIGURE 2.8: Crank-Shaft mechanism



FIGURE 2.9: 52 teeth final drive gear and 11 teeth parallel gear with 48 teeth spur gear

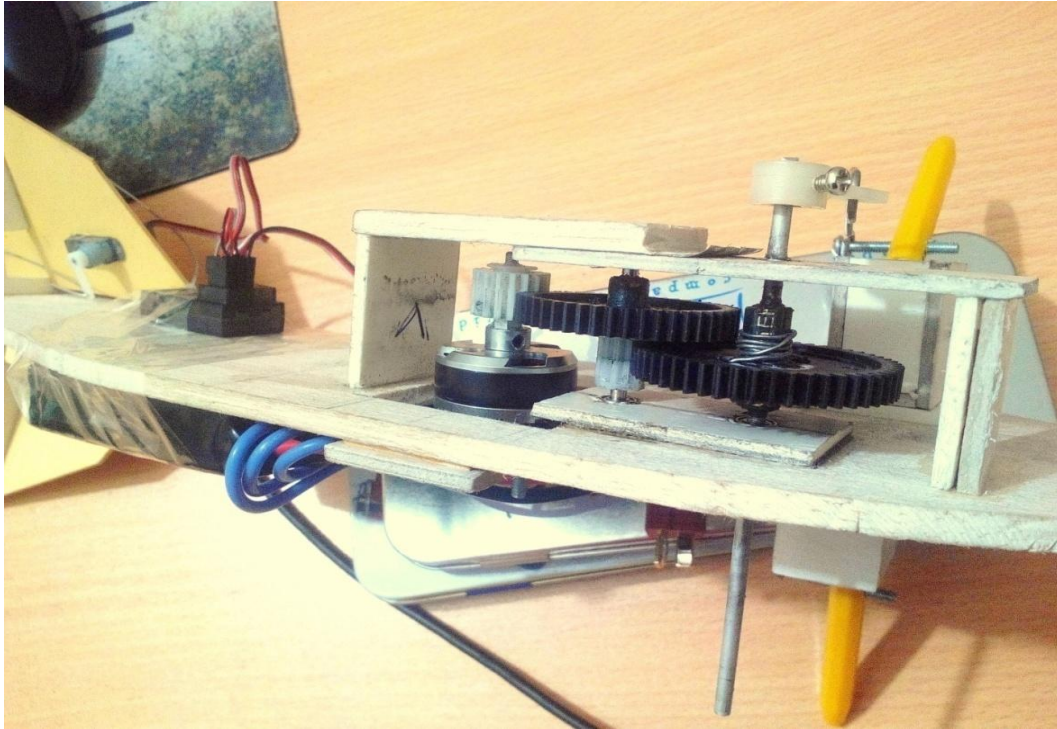


FIGURE 2.10: Upside down view of the gearbox

2.4 Power Source

2.4.1 Motor

The model is powered by a Turnigy L2205 brushless DC motor. Brushless motors are typically 85-90% efficient whereas brushed DC motors are around 75-80% efficient. This difference in efficiency means that more of the total power used by the motor is being turned into rotational force and less is being lost as heat. This motor has a 1350KV(rpm/v) rpm rating and can pull max of 13.5A current at 11.1V. So it is capable to deliver 149.85W maximum power output under loaded condition and turns at a rate of 14,985rpm at no load at 100% throttle.

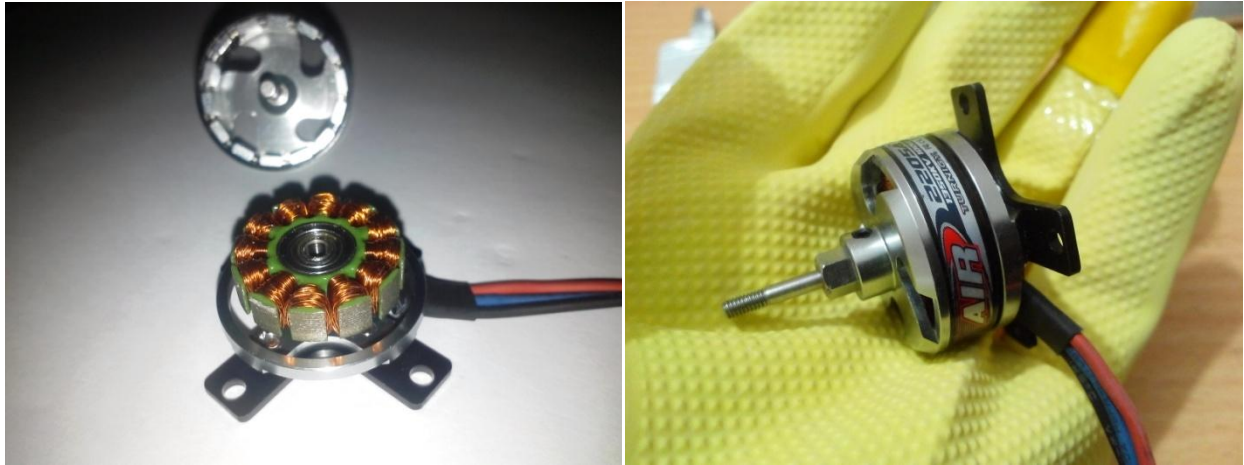


FIGURE 2.11: A Turnigy L2205 1350KV (rpm/v) Brushless Outrunner DC motor. The outer magnet can rotate and the coil remains stationary

This motor's speed is controlled by a HK SS Series brushless 18-20A electronic speed controller. It gives a 20A burst for 10 seconds and 18A continuous. ESC (Electronic Speed Control) is a device that controls the speed of the motor by turning the motor on and off. To turn on the motor the switch is kept closed which allows current to flow to the motor. If switch is open then the flow of current is stopped and the motor will slow down and eventually stop turning. Proportional throttle control is achieved by varying the amount of time the switch is on relative to the amount of time it is off. For example, for 1/2 throttle, the switch is on half the time.

In order to achieve smooth throttle response, this switching must occur several times per second. The motor operates safely with 13.5A so we must limit our maximum current output from the ESC to help the motor from burning out under critical load conditions. The ESC itself has battery eliminating circuit to power up our receiver module and has a low voltage cut-off for Li-po to prevent a permanent damage of the Li-po battery that is used to power up the whole system.



FIGURE 2.12: Brushless electronic speed controllers and Li-Po batteries. A 18A Brushless ESC and a 3S 1100mAh Li-po have been used as the power source

2.4.2 Battery

LiPo or Lithium Polymer batteries have a much more even delivery of power during use, giving more consistent speed and punch throughout each cycle. They also have little or none of the memory effect that NiMH and NiCd battery packs suffer from. In short, LiPo's provide high energy storage to weight ratios in an endless variety of shapes and sizes. For the past few years, NiMH stick and saddle packs have dominated the RC world, but now LiPo's are fast becoming the norm for many RC enthusiasts [19]. We are using a 3S-25C 750mAh Lipo battery.

For max current draw of 18.750A the battery will survive approximately for 2.4 minutes. This is calculated by dividing 750mAh by 60 min. Then multiplying the C rating with the result gives 312.5mA as the maximum discharge in a minute. This C rating of the battery indicates it can safely discharge at a rate of 25 times more than the capacity of the pack. 312.5mA/min is the maximum discharge rate for the battery. Now dividing 750mAh by 312.5mAh gives the total discharge time 2.4minutes.

2.5 Tail Design

To control the movement of our ornithopter and for the vertical and horizontal stability tail is needed. The most efficient tail design is modern airplane like tail. Our ornithopter has a V shaped tail that may have similarity with bird's tail but operates in a different way. The area of the tail should be one third of the total wing area. Nathan Chronister's recommendation is, it should be like this and we got this in a conversation with him. The tail is actually a joint figure of two main sections. Each of which has two more sections. One is fixed with the fuselage and another is attached with the fixed section by nylon hinges.



FIGURE 2.13: Top view of tail (left image) and inside view of tail (right image)

The fixed portion is made from 2mm plywood and the moving section is made of 0.5mm balsa wood sheet. Balsa is super light weight and strong enough to be selected for this design implementation. Other things used here are 2 units of 4.3g micro servo motors, one pair of control horns, push rods. For joining we used super glue. The tail is slightly below of the main wing to handle the flow of the air passing through the body. The tail is slightly inclined at an angle 20° . Both side tails cancels each other's effects caused by this inclination. For details we are showing the image of it. So when the moving half portion of the total tail rises upwards it directs the bird to bank at an angle of 20° . We kept the banking angle relatively low for our first model. A higher banking angle reduces a lot of speed and need sufficient thrust force and elevator operation to balance its speed. The reverse operation of the both portions gives the rolling advantage to the bird. It actually functions like ailerons found in most airplanes. Other

combinations works as elevator does. So it has four combinations which functions as ailerons and elevators.

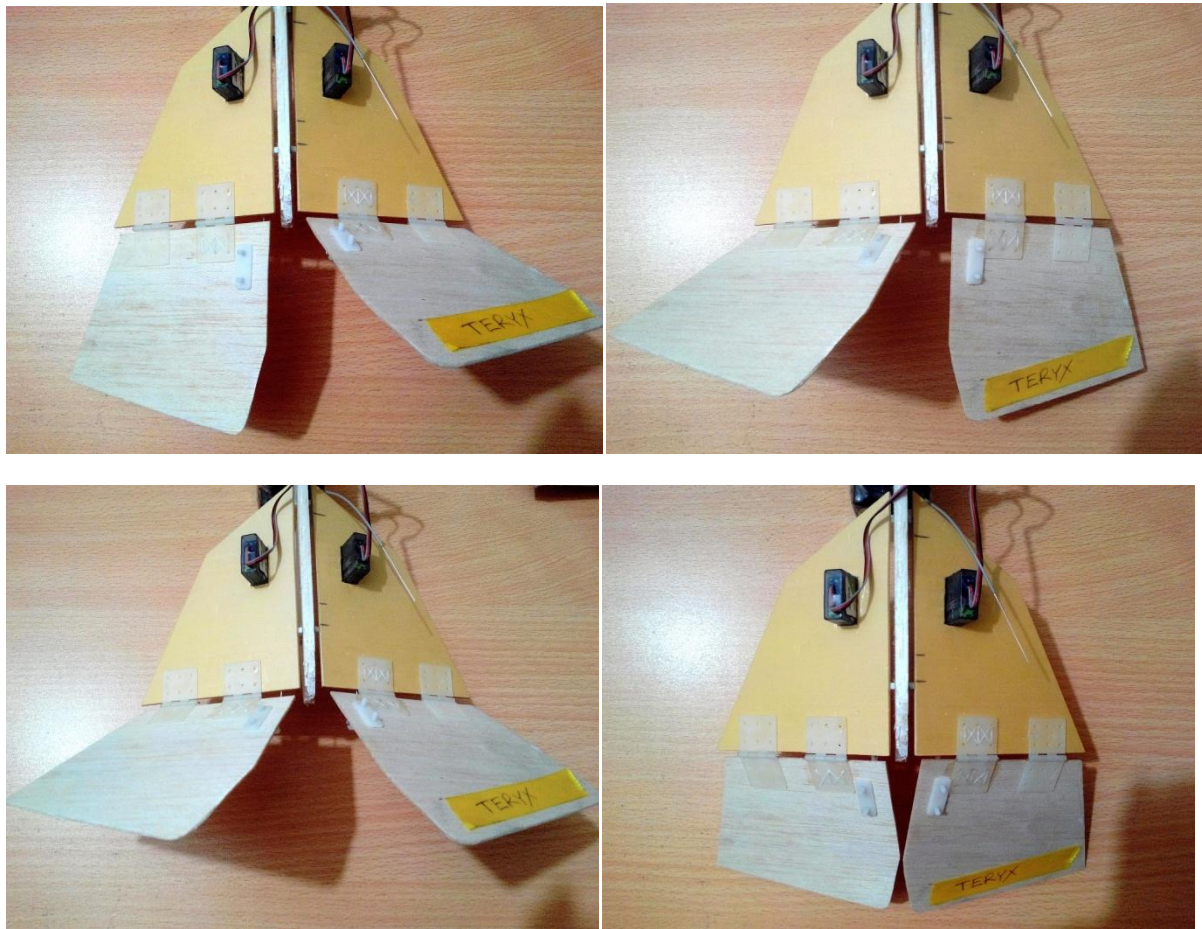


FIGURE 2.14: Tail combinations

2.6 Communication

The Turnigy 2.4GHz FHSS 5channel transmitter and receiver control our ornithopter. FHSS stands for frequency hopping spread spectrum. The drawback of this frequency selection is it becomes absorbed by other surfaces that come between the controller and the receiver as the frequency is very high. The main idea behind spread spectrum is to spread the radio transmission out over a wider range of the radio spectrum - thus the name SPREAD SPECTRUM. This makes a spread spectrum signal much less likely to run into interference or jamming issues that are common with all narrow band radio transmissions. But FHSS that have also DSSS technology

gives a better operational range that is the limitation for FHSS technology. However FHSS with DHSS transmitter and receiver was not our primary choice to test flies our bird.



FIGURE 2.15: Turnigy 2.4GHz Transmitter (left) and receiver (right)

A FHSS is enough to meet that test requirements. It's standard is far most good from typical AM, FM controller that are found in normal cheap remote control toys in market and a bit lags from the performance of a FHSS and DSSS controllers. DSSS stands for “direct sequence spread spectrum” direct sequence as the name suggests uses random PN code sequences and picks one or more pseudo randomly selected frequencies out within the band (such as 2.4 GHz). The idea is with several randomly selected frequencies, along with random code sequences, it's very unlikely all of them would ever experience interference at the exact same time within the unique code sequence. This brings improved radio range to DSSS based controllers.[20] We want our bird to control the thrust, fly sideways and upwards. In total 3 channels are needed to control our model bird. We simply connected the ESC controller to the thrust channel of the receiver and elevator and rudder control was done by putting those channels in elevator and aileron channels in the receiver module.

As the frequency of the transmitter is very high, its antenna is small in contrast with the AM/FM transmitter and the antenna has a null region on the area pointed by the antenna tip. So for better controlling we need to take care that the antenna tip point is not directed to the model in flight time.

2.7 Main Frame

The main frame holds wings, gear assemblies, electrical system, radio receiver and tail components. Glass fiber or carbon fiber plate is perfect for this build. But as these parts are not yet available in our country and overseas order take a longer period of time to delivery and not cost effective we used balsa wood frame as a replacement of that material. But it has a downside. All the gear assemblies need a strong as well as light frame to handle the tremendous vibrations of a 100W motor and gear train. Balsa wood is not that type though it is ultra light weight. Drilling in balsa is not possible as the wood is not so dense and cutting the wood requires special machines. Even hacksaw is not appropriate tool for that job. We have used a 5mm thick balsa frame which we cut according to our design purpose with balsa cutter and to hold gear axels and bearings a thin layer of tin was glued with adhesive. This thin layer can provide additional strength to the frame and improves the tolerance or temper.

Two small balsa pieces was used to hold the gear axels from the both side of the frame. The motor was mounted with frame with screws and the drive pinion was linked with the gear train. We used bearings with axels to avoid frictional energy lose and noise reduction. Bearings are placed in balsa wood with adhesive in perfect alignment. The wing spars are linked with the body with strong hinges to tolerate the strong jerks and wing momentum in full throttle. To handle large amount of torque the joints should be also strong. The frame's one side was cut according to the design specific angle of attack. And there are points to stick the wing film with the frame. The batten rods have the connectivity with the main frame also. A 3D image of the frame can describe the whole story very clearly. To give the UAV a bird looking we cut the frame shape similar to the appearance of a bird. We used super glue, metal solution, nuts and bolts, tin sheet, balsa cutter, paper cutter to make the frame for the ornithopter. Before we cut the frame a paper sketch of the design was attached with the balsa wood sheet to cut the frame accurately.

To prepare the ornithopter for its first flight it is important to find the center of gravity point of the body to place the li-po battery and other electrical components to balance the weight. We got our CG point at 50% of the root chord from the leading edge of the wing.

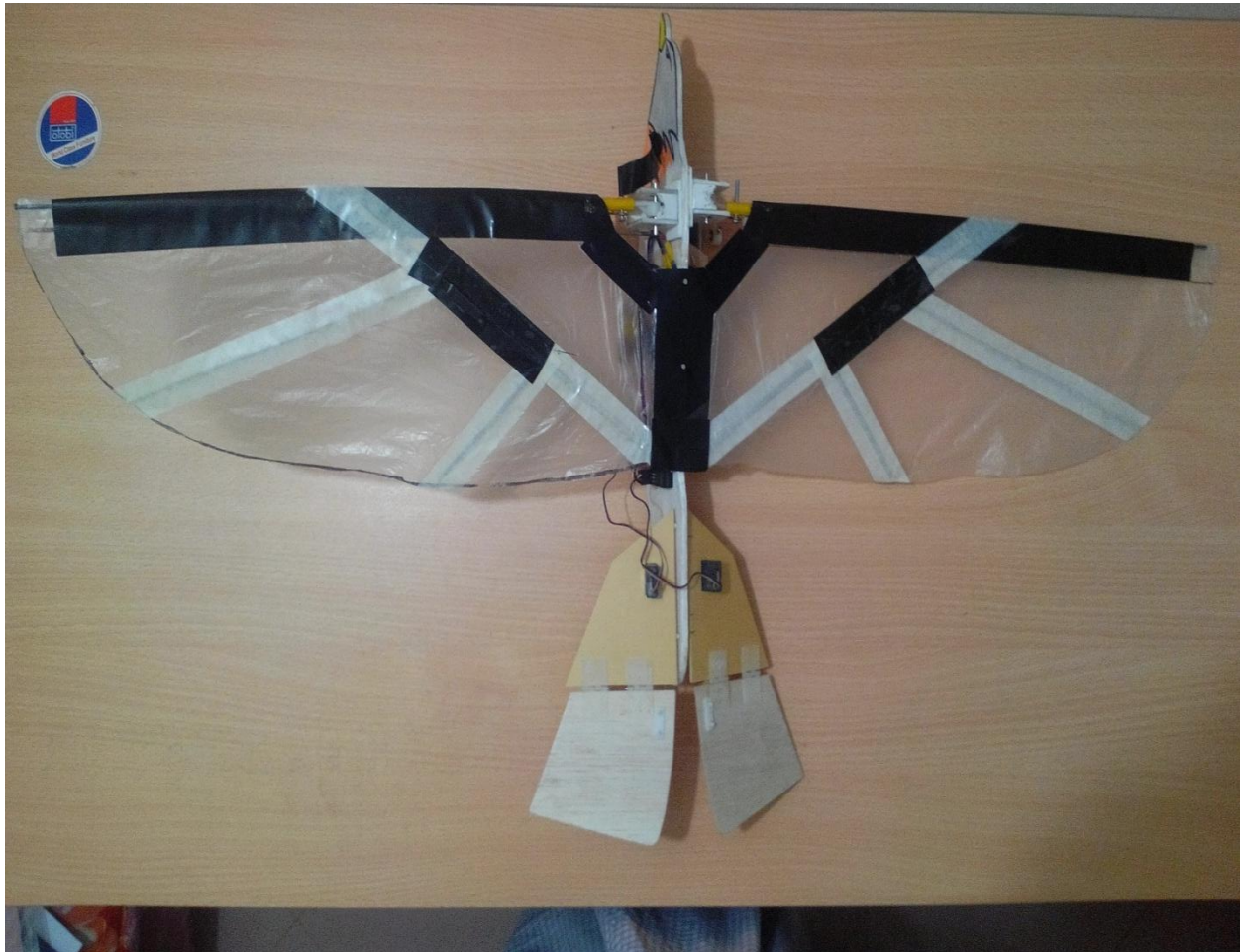


FIGURE 2.16: The image of the model

CHAPTER 3-Conclusion

3.1 An outline of future work

At present our ornithopter is still in hanger for its preparation for first flight. Still we have scarcity of necessary components. Things are so sophisticated and also the weight is important and should be taken under intensive care. In future we think we will be able to find the best alternative components and design ideas that can dramatically change the complexity of the crank shaft mechanisms. Or we can build our required parts by our own with proper tools and materials. Instead of balsa wood we are planning to use carbon fiber or fiberglass sheets and for cutting we want to use CNC technology for design efficiency and accuracy. Addition with this we want to give our bird a gliding or soaring capability. There is a nice device for it named GLDAB. It is a programmable gliding device that helps to soar the ornithopter to glide at a fixed wing position. It works in conjunction with a mechanical ratchet. The unit should be inserted between the RX and the ESC. The magnetic detector connected to the unit is used to detect the stop position. The magnet should be fixed onto the main gear of the mechanism. The magnetic detector and the magnet should be aligned when the mechanical ratchet is engaged.

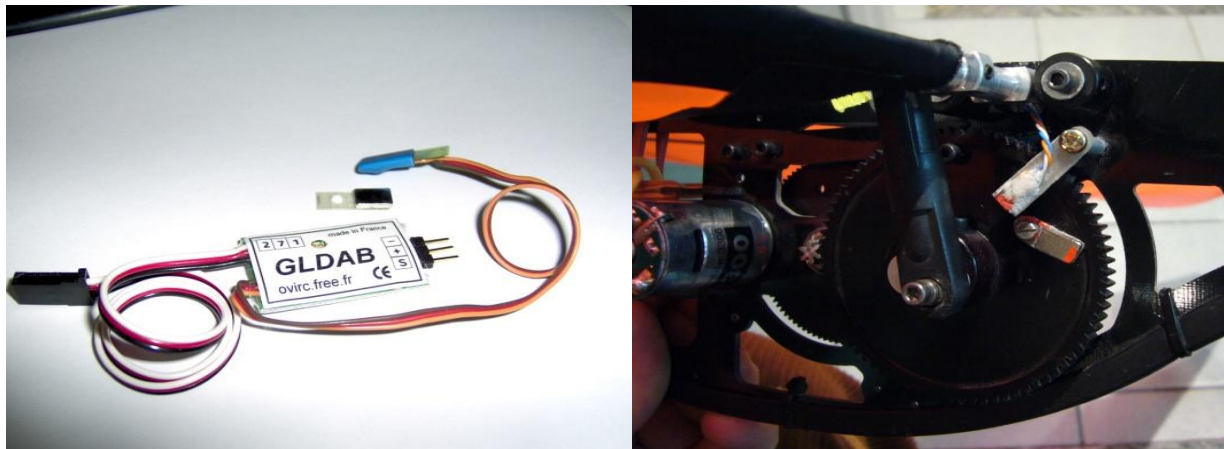


FIGURE 3.1: GLDAB gliding device and mechanism



FIGURE 3.2: Soaring of a bird

This gliding technique by GLDAB has a shortcoming that it fails to detect the magnet position in high speed. But it is easier to implement. Better option can be a mechanical glide lock mechanism that will lock the wings in gliding position at high speed also. We also have plans to use autopilot modes and FPV telemetry and more payload capacity in our bird but before that we need to engage ourselves to improve its aerodynamics, weight, more efficient wing designing and eliminating power consumption at a good degree. Its top improvement in control techniques can give it the eligibility to use it in spying or mapping an area under critical situations and to flatter the enemy eyes in battlefield or scaring away runway birds for traffic safety. The big model can take the lead to miniaturizing the bird into a small insect that will perform operations where visibility of it might create a major problem.

3.2 Conclusion

Building a flying UAV is always a matter of great challenge and interest for us. We are looking for more laboratory tools and set-ups for this. Because the measurements of lifts and drag forces, observing the aerodynamics of the object can be a matter of great fun but without having perfect or standard lab setup for this types of experiments are absolutely funny. Because we can't see what is happening to the air without a wind-tunnel. So we are working to make this for our own. We are looking for more efficient computerized cutting and drilling tools. Today's toy can turn the whole world to a next stage in tomorrow. The great example is drone technology as we can see at present. Poor countries are lagging day by day from those countries who can afford those expensive equipments. This is the time to build ours or to find a counter of those types. Ornithopter's efficiency and use of it is still now in experiment level and living in thoughts of the enthusiasts and hobbyists. Articulated flying models are coming out now. We should realize that this is just another way of flying. We think one day we will be able to copy the flying of a real bird. This world is advanced in flight systems a lot but we must remember that though we are superior in building attractive flying models but we are far more behind from copying the flight technique of a fly catcher. And for drone applications maneuverability is a great concern always. We can ignore it for passenger flying vehicles considering many reasons behind but for drone applications with matching operational purpose this fake birds can be a deadly weapon.

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