Design and Development of an Ornithopter for Surveillance

A PROJECT REPORT

Submitted in partial fulfillment of the
requirements for the award of the degree

of
BACHELOR OF TECHNOLOGY
in

MECHANICAL ENGINEERING

Submitted by:
Alok Ranjan, Ayush Agarwal & Himanshu Bhagat

Guided by:
Dr. Shailesh Kundalwal (Assistant Professor)
Dr. Indrasen Singh (Assistant Professor)

INDIAN INSTITUTE OF TECHNOLOGY INDORE
DECEMBER 2017

CANDIDATE'S DECLARATION

We hereby declare that the project entitled "**Design and Development of an Ornithopter for Surveillance"** submitted in partial fulfillment for the award of the degree of Bachelor of Technology in Mechanical Engineering completed under the supervision of **Dr. Shailesh Kundalwal** (Assistant Professor, Mechanical Engineering) and **Dr. Indrasen Singh** (Assistant Professor, Mechanical Engineering)**, IIT Indore** is an authentic work.

Further, we declare that we have not submitted this work for the award of any other degree elsewhere.

Alok Ranjan **Ayush Agarwal** **Himanshu Bhagat**

CERTIFICATE by BTP Guide(s)

It is certified that the above statement made by the students is correct to the best of my/our knowledge.

Dr. Shailesh Kundalwal **Dr. Indrasen Singh**

(Assistant Professor) (Assistant Professor)

PREFACE

This report on "**Design and Development of an Ornithopter for Surveillance Purpose**" is prepared under the guidance of Dr. Shailesh Kundalwal & Dr. Indrasen Singh.

In this report, we have given an elaborate insight in the design of a mechanical bird, also known as **Ornithopter** to be used for surveillance in civilian as well as military purpose. In order to build it, one has to be proficient with basics of mechanics, electronics and programming.

We have tried our best to explain this content to the reader in a lucid and comprehensive manner. We have also added 3-D models and experimental results to make it more illustrative.

Alok Ranjan, Ayush Agarwal & Himanshu Bhagat
B.Tech. IV Year
Discipline of Mechanical Engineering
IIT Indore

Acknowledgements

We wish to thank **Dr. Shailesh Kundalwal & Dr. Indrasen Singh** for their kind support and valuable guidance. We would also like to acknowledge Mr. Anand Petare and his staff at **Central Workshop** of IIT Indore for providing their sincere cooperation and guidance to our project.

It is with their help and support that we were able to complete the design and technical report. Without their support this report would not have been possible.

Alok Ranjan, Ayush Agarwal & Himanshu Bhagat

B.Tech. IV Year

Discipline of Mechanical Engineering

IIT Indore

Abstract

The desire to fly like birds is as old as humanity itself. Human beings flying with the help of fixed-wing aircrafts of various kinds have been able to fly for more than a century. An **"Ornithopter"** is flying machine that uses an insect or bird type flapping wing motion to develop required lift and thrust to fly. In this paper, several ornithopter prototypes that mimic the flapping motion of bird flight are developed, and the lift and thrust generation characteristics of **semi- elliptical wing design** are evaluated. This project is focused on the spar arrangement and material used for the wings that could achieve improved performance. The feasibility and effectiveness of several flapping mechanisms is evaluated. Several **servo motors** of different torques and **an Arduino** (microcontroller) to control the flapping motion are employed. The effect of several parameters like forward speed, flapping frequency and amplitude on lift and thrust are observed and the results are presented in this report.

The final ornithopter prototype weighs only 650gms, has a wing span of 140cm, that can flap at a maximum frequency of 2 Hz with 30 degrees as wing amplitude. It provides around 814 gm-f as lift force and experiences 68 gm-f of drag force theoretically.

Table of Contents

Candidate’s Declaration

Supervisor’s Certificate

Preface

Acknowledgements

Abstract

List of figures

CONTENTS

Chapter 1 – Introduction

Chapter 2 – Terminology

Chapter 3 – Aerodynamics of flapping wings

3.1 – Wing kinematics

3.2 – Forces generated due to flapping wings

3.3 – Downgrading factors

3.4 – Aerodynamic modelling

Chapter 4 – Design and Material selection

4.1 – Wing Design

4.2 – Calculation of Lift and Drag force

Chapter 5 – Flapping Mechanism

5.1 – Mechanism 1: Dual-shaft motor based flapping mechanism

5.1.1 – Components

5.1.2 – Prerequisites

5.1.3 – Assembly

5.1.4 – Final design specifications

5.1.5 – Working

5.1.6 – Advantages

5.1.7 – Drawbacks

5.1.8 – Results and conclusion

5.2 – Mechanism 2: Servo motor based flapping mechanism

5.2.1 – Components

5.2.2 – Prerequisites

5.2.3 – Assembly
5.2.4 – Final design specifications
5.2.5 – Working
5.2.6 – Advantages
5.2.7 – Drawbacks
5.2.8 – Results and conclusion
Chapter 6 – Programming
Chapter 7 – Results and Conclusion
Chapter 8 – Applications and future scope
Chapter 9 – References

List of Figures

Fig. 1 - Atlantic Puffin Flying

Fig. 2 - Rubber Band Powered Ornithopter

Fig. 3 - Terminology of an aerofoil

Fig. 4 - Representation of primary forces acting on an aerial object

Fig. 5 - Representation of a wing

Fig. 6 - Motions of a bird

Fig. 7 - Forces during downstroke and upstroke

Fig. 8 – Down-washing effect

Fig. 9 – Wing Form for Analytical Study

Fig. 10 – Forces on each section of the Wing

Fig. 11 - Representation of dual-shaft mechanism and wing frame

Fig. 12 - Dual-shaft motor based flapping mechanism

Fig. 13 - Representation of servo motor based mechanism and wing frame

Fig. 14 - Servo motor based mechanism

Fig. 15 – Schematic representation of the circuit employed

Chapter 1

Introduction

Natural fliers like birds and insects have captivated the minds of human beimgs throughout history. The ease and grace with which they fly in the air surpasses the state of the art in aircraft and their control systems. This is not to say that modern aircraft designs are ineffective, they are excellent in many aspects. Propellers and turbines are very efficient methods of producing thrust and airfoils efficiently produce lift.

However, there is a growing need for miniature flight vehicles with multifunctional capabilities such as Micro Air Vehicles(MAVs) for both civilian and military surveillance. Flapping wing flight of birds provides us with a sophisticated example of utilizing **unsteady aerodynamics** to mechanize the miniature flight structures at low Reynolds numbers. Birds and insects, who flap, use different methods to produce lift and thrust. Flapping micro air vehicles based on birds are known as 'Ornithopter' whereas those based on insects' flight is known as 'Entomopter'.

However flapping wing flight is way more difficult than fixed wing flight. For an aircraft with fixed wings, only forward motion is necessary to sustain the body with the induced aerodynamic lift. For the flapping flight, the wing not only has a forward motion but also the up and down flapping. In the down stroke flapping, the wing is fully extended and produces both lift and thrust at the same time. During the up stroke, some part of the wing is folded to reduce the moment of inertia and the drags of the wings. The wings are also twisted during the flapping to vary the angle of attack for various flying motions.

Fig. 1 - Atlantic Puffin Flying

The potential advantages of FMAVs over fixed winged flight include:

- **Increased maneuverability –** By varying their angle of attack (explained later) and tail movements, birds (normally with high lift to drag ratio, like albatross) are able to perform various maneuvers in air which are not possible with fixed wing flights.

- **Lower Power consumption –** FMAVs can produce lifts without flapping when the wings are held out to the side of the body in air flow. It is due to difference in pressures above and below the wings which produce the required lift.

- **Camouflage –** Because of its excellent resemblance to a bird, it is difficult to spot and can be used as an excellent spying instruments in military applications.

- **Easier Direction Control**

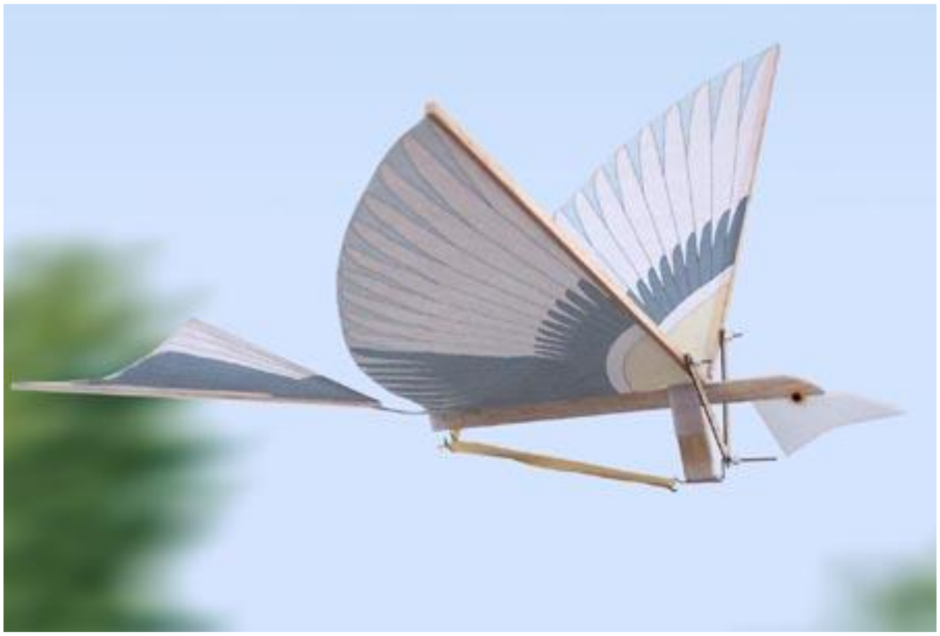


Fig. 2 – Rubber-band Powered Ornithopter

Chapter 2

Terminology

1. **Aerofoil –** An aerofoil is a term used to describe the cross-sectional shape of an object that, when moved through a fluid such as air, creates an aerodynamic force.

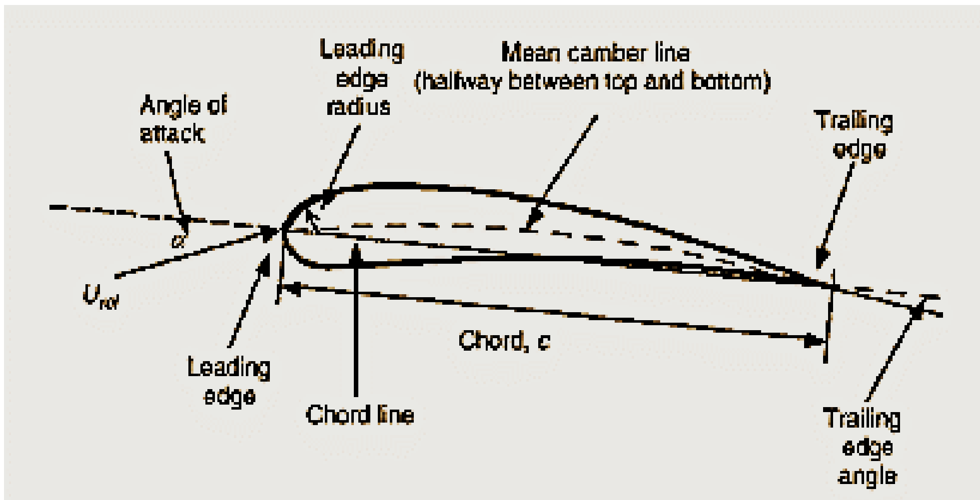


Fig. 3 - Terminology of an aerofoil

2. **Viscosity –** Viscosity of a fluid is the measure of its resistance to gradual deformation by shear stress or tensile stress.
3. **Compressibility –** Compressibility of any substance is the measure of its change in volume under the action of external forces.
4. **Camber –** Camber is the asymmetry between the two acting surfaces of an aerofoil, with the top surface of a wing commonly being more convex.
5. **Chord line –** It is a straight line connecting the leading and trailing edges of the aerofoil.
6. **Chord –** It is the length of the chord line from leading edge to trailing edge and is the characteristic longitudinal dimension of an aerofoil.
7. **Mean Camber Line –** It is a line drawn halfway between the upper and lower surfaces. The chord line connects the ends of the mean camber line.
8. **Leading edge –** It is the front edge of an aerofoil.
9. **Trailing edge –** It is the rearmost edge of an aerofoil.
10. **Angle of attack –** It is the angle between the chord line of the wing of a fixed-wing aircraft and the vector representing the relative motion between the aircraft and the atmosphere.

11. **Lift –** Lift is the component of this force that is perpendicular to the oncoming flow direction. It counters the force of gravity.

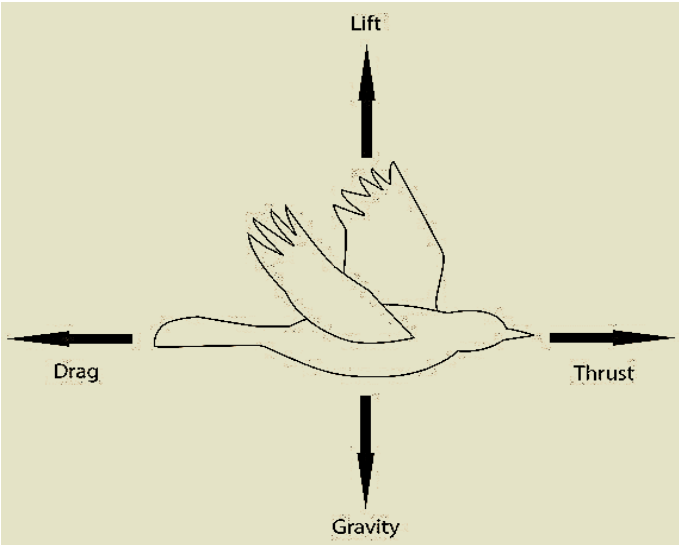


Fig. 4 - Representation of primary forces acting on an aerial object

12. **Drag –** Drag is a force acting opposite to the relative motion of any object moving with respect to a surrounding fluid.
13. **Thrust –** Thrust is the force which moves an object through the air. Thrust is used to overcome the drag of an airplane, and also to overcome the weight of a rocket.
14. **Reynold's number –** The Reynolds number is a dimensionless value that measures the ratio of inertial forces to viscous forces and describes the degree of laminar or turbulent flow.
15. **Mach number –** Mach number is the ratio of the speed of a body to the speed of sound in the surrounding medium.
16. **Center of pressure –** It is a point on a surface through which the resultant force due to pressure passes.
17. **Mean geometric chord –** The mean geometric chord is the chord of a rectangular wing having the same span and. the same area as the original wing.
18. **Mean aerodynamic chord –** Mean aerodynamic chord is the average chord length of a tapered, swept wing.
19. **Sweep angle –** The angle swept by a wing in a single flap is known as sweep angle.
20. **Aspect ratio –** The aspect ratio of a wing is the ratio of its span to its mean chord. It is equal to the square of the wingspan divided by the wing area.

21. **Downwashing –** Downwashing is the change in direction of air deflected by the aerodynamic action of an aerofoil, wing or helicopter rotor blade in motion, as part of the process of producing lift.
22. **Wing Span –** Wing span (or span) is the distance from one wingtip to the other wingtip.

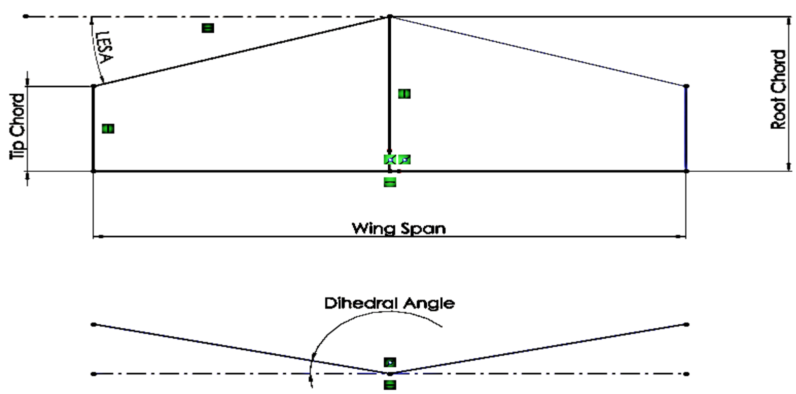


Fig. 5 - Representation of a wing

23. **Wing area –** The surface area of the wing is known as wing area.

Chapter 3

Aerodynamics of Flapping Wings

Flapping wing aerodynamics is mainly governed by unsteady aerodynamics. It's less unsteady for birds with slow flapping rate like albatross which has a higher lift to drag ratio. However, the aerodynamics is very unsteady for small birds and insects which has a high flapping rate. Most birds even use the mechanism of gliding, in which they appear to hang in the air effortlessly, gaining height with barely a twitch of wing. It is due to difference in pressure of air above and below the wings which helps them to gain height. Furthermore, while gliding, a bird can also tilt downward to increase their speed at the cost of height.

3.1 Wing Kinematics

A bird can have three types of motions with respect to three axes-:

- **Flapping** - It is the up and down plunging motion of the wing. It produces majority of birds' power and has the highest degree of freedom.
- **Pitching** - It is the turning motion of the wing along the axis which passes through the wings in the plane of the body.
- **Lead- Lag** – It's the plane lateral movement of the wing.

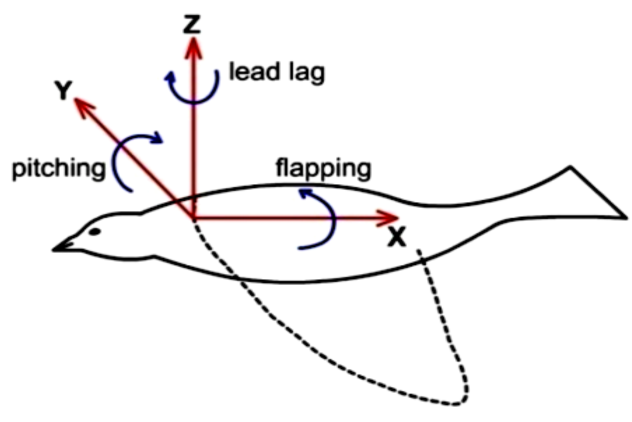


Fig. 6 - Motions of a bird

In our model, only the flapping motion of the wing was employed in order to generate the required lift and thrust.

3.2 Forces generated due to Flapping Wings

Flapping involves two motions, which are –

- **Downstroke**- It's the power stroke which provides majority of the thrust.
- **Upstroke**- It's the recovery stroke, which can also be used to provide some upward force. At each upstroke, the wing is folded inwards to minimize upward resistance.

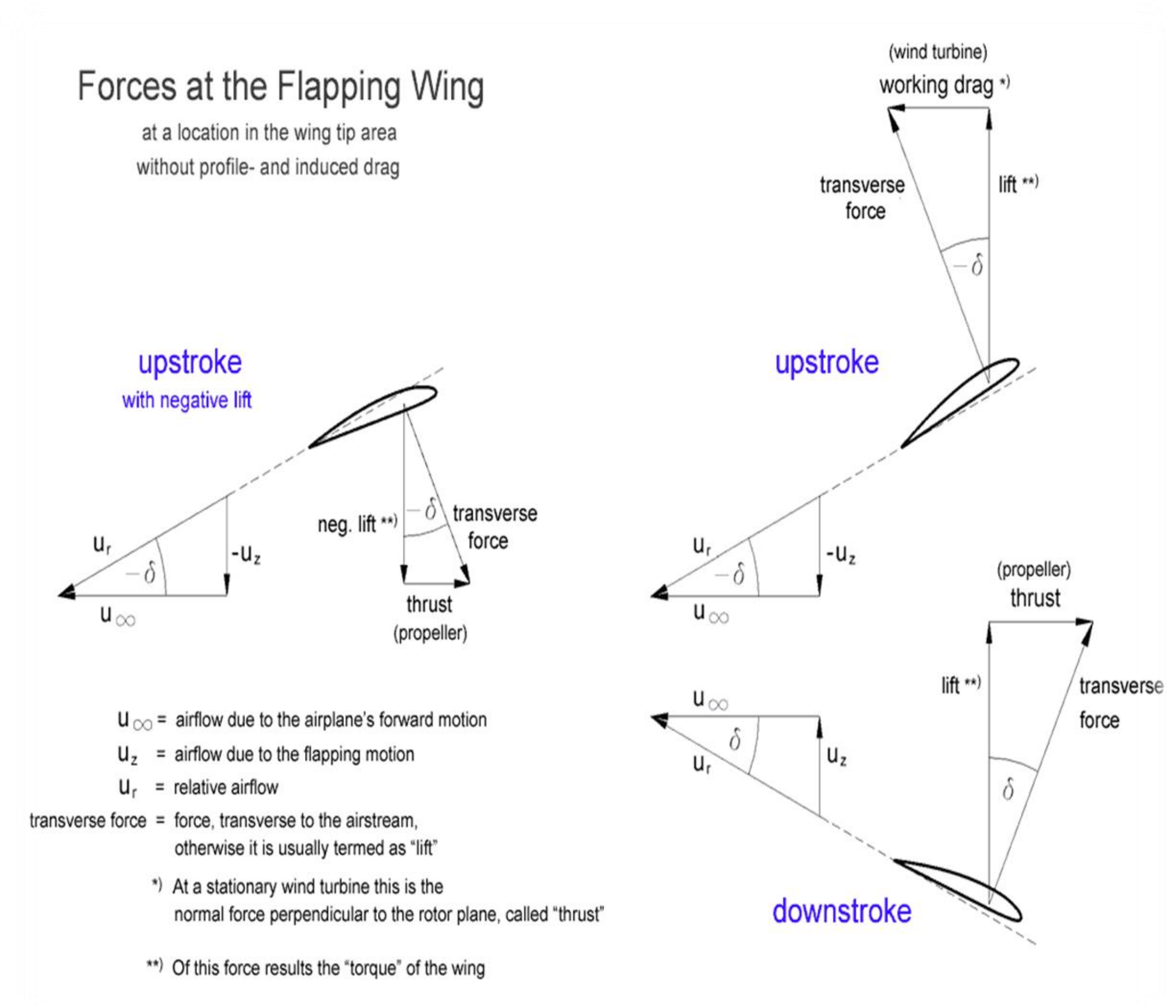


Fig. 7 - Forces during downstroke and upstroke

When the wings move up and down, they are also moving forward through the air along with the rest of the bird. Close to the body, there is very little up and down movement. Farther out toward the wingtips, there is much more vertical motion. As the bird is flapping along, it needs to make sure it has the correct angle of attack all along its wingspan. Thus, for constant forward speed, the relative angle of attack (AOA) also decreases from tip towards root. As the outer part of the wing moves downward, the lift force in the outer part of the wing is angled forward. Therefore, the bird can generate a large amount of forward propulsive force without any loss of altitude. During the down stroke the total aerodynamic force is tilted forward and has two components, lift and thrust.

During up stroke, the AOA is always positive near the root but at the tip it can be positive or negative depending on the amount of pitching up of wing. Therefore, during up stroke the inner part of wing produces aerodynamic force which is upward but tilted backwards producing lift and negative thrust.

3.3 Degrading Factors

- **Downwashing –** Near the tips of the wings, the air is free to move from the region of high pressure to the region of low pressure resulting in the formation of counter rotating vortices. Effective angle of wings is decreased giving an additional downward facing component to the aerodynamic force over the entire wing.

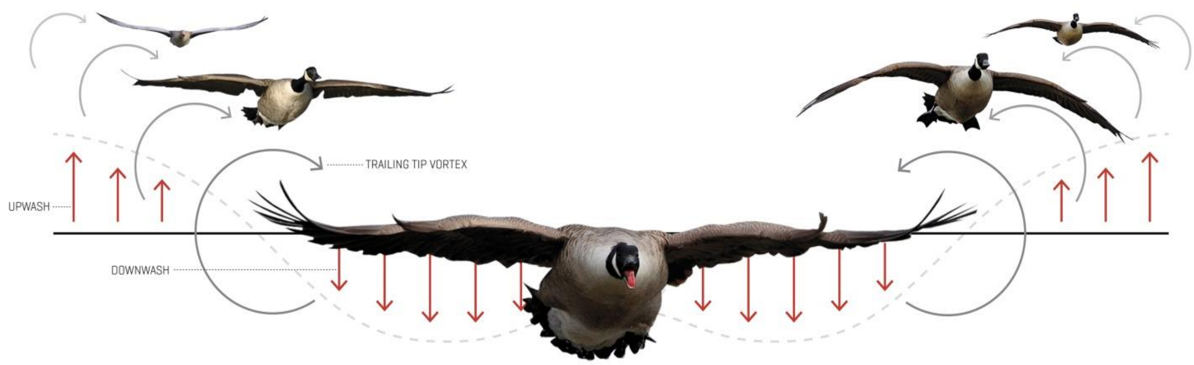


Fig. 8 – Downwashing effect

- **Von Karman Vortex Street –** It's a repeating pattern of swirling vortices caused by the unsteady separation of flow over bluff bodies. Vortices are shed into the downstream flow from alternate sides of the body, giving the appearance of oppositely signed vortices.
- **Skin Friction –** Frictional force acting due to drag.

3.4 Aerodynamic Modelling

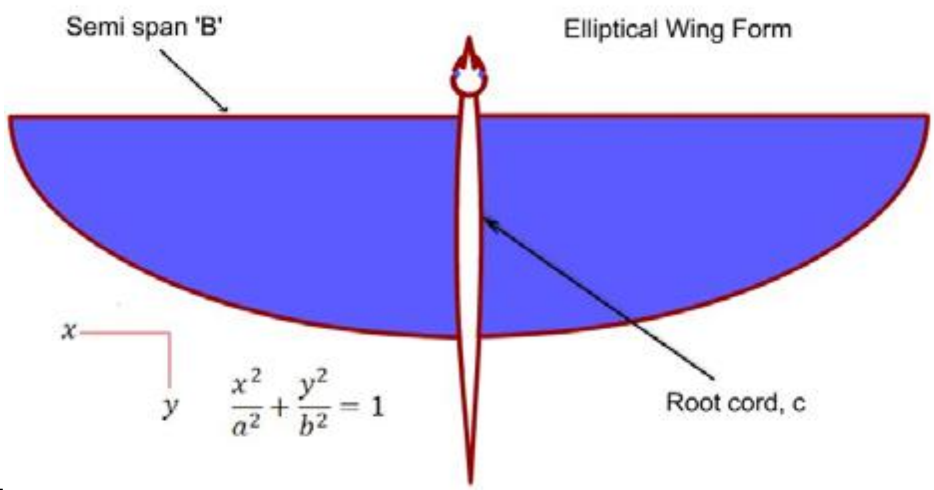
The analytical modelling has been done using **Blade Element Analysis** which converts a time dependent problem into a sequence of independent, steady state problem and steady state aerodynamics has been used to calculate the forces. Because of the finite wing span, there is reduction in the net aerodynamic forces because of unsteady wake-effects. These effects can be accounted for by using **Theodorsen** function. The assumptions which were taken are-:

- Wings are made of flexible membrane with spar at leading edge and wing form is semi-elliptical.

- Only flapping would be induced by the power train system with equal up/down flapping angles.

- The front spar will act as a pivot for pitching movement, caused by the aerodynamic/ inertial loads.

- Upstroke and down strokes have equal time duration.



F

Fig. 9 – Wing Form for Analytical Study

The section lift coefficient due to circulation (Kutta - Joukowski condition for flat plate) is given by -:

$C_{l\text{-}c} = 2\pi\, C(k)\, \sin\alpha_{eff}$

Where α_{eff} is the effective angle of attack and C(k) is the Theodorsen Lift Deficiency factor which is the function of Reduced frequency k and can be calculated using the following functions-:

$C(k) = \sqrt{F^2 + G^2}$

$F = 1 - \frac{C1.k^2}{\sqrt{k^2 + C2^2}}$

$G = 1 - \frac{C1.C2.k}{\sqrt{k^2 + C2^2}}$

C1 and C2 are given by-:

$C1 = \frac{0.5*AR}{2.32+AR}$

$C2 = 0.181 + \frac{0.772}{AR}$

The section lift can this be calculated by-:

$dL_c = \frac{1}{2}\rho V^2 . C_{l-c}.c.dr$

where c and dr are the chord length and width of the element of wing under consideration. V is the relative velocity of bird with respect to the air. On performing the integration for the entire wing, c.dr changes to the total area of the wing.

The drag force has two components, profile drag dD_p and induced drag dD_i. These are calculated as under-:

$dD_p = \frac{1}{2}\rho V^2 . C_{dp}.c.dr$

$dD_i = \frac{1}{2}\rho V^2 . C_{di}.c.dr$

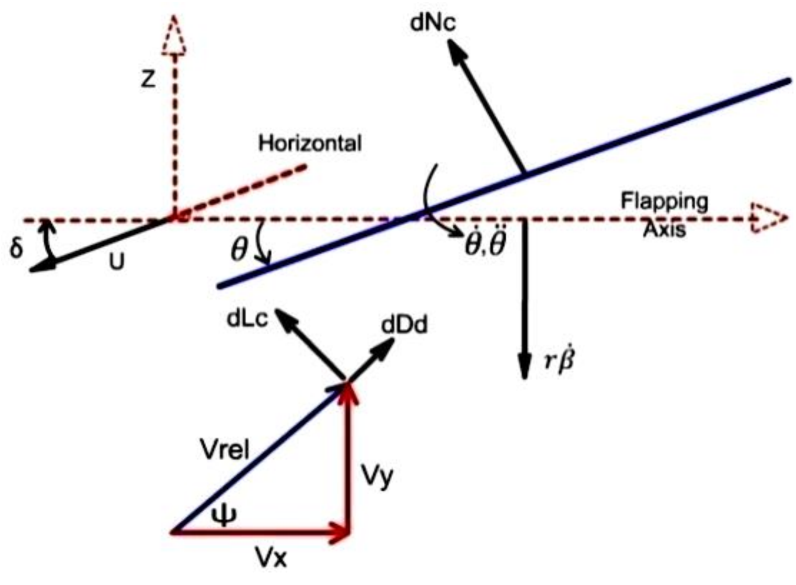


Fig. 10 – Forces on each section of the Wing

where Drag coefficients are given as under-:

$\cdot C_{dp} = K.\ C_f$

$C_f = 0.445(\log_{10} Re_{ref})^{-2.58}$

$$C_{di} = \frac{\sqrt{Clc^4}}{e\ \pi\ AR}$$

where C_f is the skin friction coefficient for flat plate and K is the factor to account for unsteady flight. Maximum value of K will be used as 4.4. C_{di} is induced drag coefficient. The e is the efficiency factor of the wing and is 0.8 for elliptical wing. Total section drag is thus given by: -

$dD_d = dD_p + dD_i$

whose total value can be found using Integration.

Chapter 4

Design & Material Selection

4.1 Wing Design

In order to choose the right cross-section of the spars which can sustain heavy torque and air pressure, we compared the **elastic section modulus(S)** of different cross-sections. We know that

$$\sigma_m = \frac{M}{S}$$

where σ_m is the maximum normal stress and M is the bending moment. Now for the rectangular cross-section, the section cross-section came out to be the largest for given dimensions which means it can sustain for greater σ_ms.

The length of the spar was calculated using the bending moment diagram with the maximum torque of 5N-m on both sides. It was calculated for two materials and results were compared-:

- **E-Glass Fiber-**

  The properties and results are demonstrated-:

  Density- 2.54gm/cm^3
  Yield Strength- 3400 MPa
  Cross-section- 2 mm^2

  After calculations, the maximum length which can be employed was 11m whose weight will be 56 g

- **Balsa Wood-**

  The properties and results are demonstrated-:

  Density- 0.16 gm/cm^3
  Yield Strength- 14.2 MPa
  Cross- section- 2mm^2

  After calculations, the maximum length which can be employed is around 1.2 m and weight is 0.384 g.

Since the difference in weights between balsa wood and glass fiber is more than 100 times, Balsa wood is preferred. Furthermore, there is a huge difference in their cost as well.

A semi-elliptical wing design whose semi-major axis will be 70cm (length of longest spar) and semi-minor axis will be 50 cm (length of fuselage) was designed by comparing the forces as given below –

4.2 Calculation of Lift and Drag Force-

Total area of the wings- 0.55 m^2

Total Weight of the model (mechanism 2)- 650gm

Wing Span- 1.4 cm

Flapping Frequency- 2 Hz(assumed)

Relative Velocity- 2m/s

Density of air – 1.225 g/cm^3

Wing Amplitude – 30 degrees

Using the formulae explained in the previous section, we calculated the Lift and Drag force which came out to be 814gm-f and 67.9 gm-f theoretically.

Chapter 5

Flapping Mechanism

To provide flapping motion to the wings of the ornithopter, two different mechanisms were employed. They are explained in detail below.

5.1 Mechanism 1: Dual-shaft motor based flapping mechanism

This was the very first mechanism that was employed. It was chosen because of its simplicity. In this mechanism, a single dual-shaft DC motor is used to flap both wings.

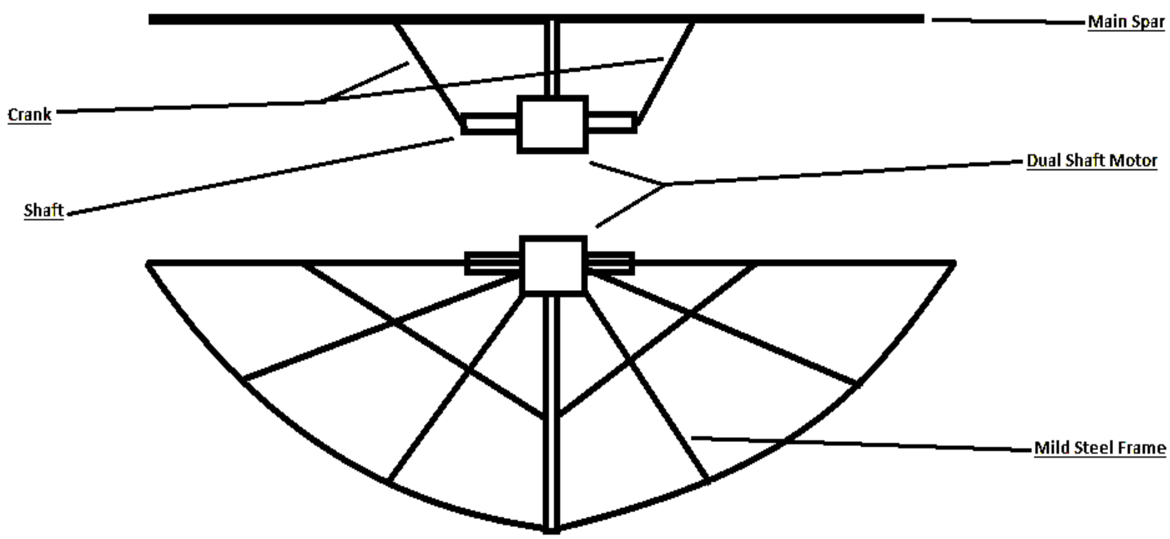


Fig. 11 - Representation of dual-shaft mechanism and wing frame

Fig. 12 - Dual-shaft motor based flapping mechanism

5.1.1 Components

The various parts of the mechanism are as follows:

1) Motor

Type = BO (Battery Operated) Dual-shaft DC motor

Weight = 30 g

RPM = 800

Working Voltage = 3V to 9V

Torque = 1.9 kg-cm

2) Frame

Material: Acrylic

Size: Length 16 cm, Width 7 cm, Thickness 0.3 cm

Density: 1.18 g/cm^3

3) Wing Spars

Cross section: Circular

Material: Mild steel

Density: 7.85 g/cm^3

Dimensions: Diameter 1.5 cm, Lengths – 30 cm*2, 15 cm*2, 20 cm*2, 16 cm*2, 21 cm*2

4) Wing fabric

Material: Nylon

5.1.2 Prerequisites

1) Wing: Wing frame is constructed by joining the mild steel rods of appropriate lengths by oxy-acetylene gas welding. The fabric is attached at various positions to the frame with the help of cyanoacrylate adhesive.

2) Frame: Acrylic sheet is cut using acrylic cutter to obtain required dimensions. Holes of various diameter as per requirement are drilled at various locations.

5.1.3 Assembly

- The motor is fixed to the frame using nuts and bolts.
- Wings are also fitted to the frame using circular fixtures.
- Two circular acrylic plates are fitted on the shaft of the motor on both sides.
- To the circular plates, an acrylic strip is connected at one end while the other end is connected to the main spar of the wing in such a way the rotary motion is possible at both joints.

5.1.4 Final Design specifications

Weight: 200g

Flapping angle: 60deg (10deg upstroke and 50deg downstroke)

Flapping frequency: 4 flaps/sec

Wing span: 60 cm

Wing area: 450 cm^2

5.1.5 Working

The working of the mechanism is similar to that of the crank-rocker mechanism, where the circular plates acts like a crank, acrylic strip acts as a coupler and the main spar of the wing acts like a rocker.

When the motor is turned on, the main spar of the wing starts oscillating which provides flapping motion to the wing.

5.1.6 Advantages

- Final design is light weight.
- Building of custom gearbox is not required.
- Design is simple and easy to manipulate.
- Power consumption is low as a single motor is used.

5.1.7 Drawbacks

- There is friction between wing spar and acrylic strip due to sliding motion which causes unnecessary loss of transmitted power.
- Torque of motor is less (only 2 kg-f) against air pressure.
- Repetitive failure of low quality plastic gears inside motor takes place due to loading.
- Lift provided is less due to small wing span and wing area.

5.1.8 Results and Conclusion

This design was not able to provide continuous flight because of the following reasons:

1. Lift provided was less due to small wing span and wing area.
2. Torque provided by the motor was not sufficient to counter the weight of the structure in air.

5.2 Mechanism 2: Servo motor based flapping mechanism

After the failure of the dual-shaft motor based mechanism, it was decided to change the design. In the following design, instead of using a single dual shaft motor to provide flapping motion, two servo motors are used to provide flapping motion to both wings separately.

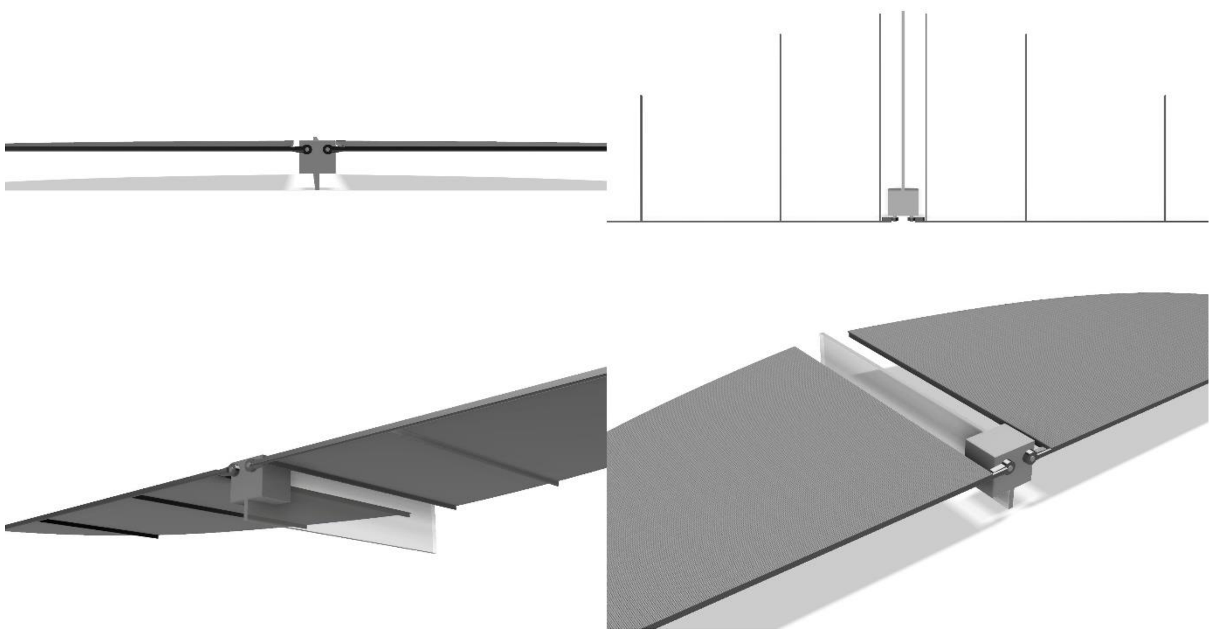


Fig. 13 - Representation of servo motor based mechanism and wing frame

Fig. 14 - Servo motor based mechanism

5.2.1 Components

Various parts of the mechanism are as follows:

1) Motor

Type: 2 servo motors MG996R

Voltage: 3V to 7V

Torque: 9 to 11 kg-cm

Speed: 0.19 to 0.15 sec/60 deg

2) Frame

Material: Acrylic

Dimensions: Length 50cm Width 6 cm Thickness 0.3 cm

Density: 1.18 g/cm^3

3) Wing spars

Material: Balsa wood

Density: 0.34 g/cm^3

Cross section: Rectangular ==> T-shaped by joining two spars transversely

Dimensions: Width 1 cm, Thickness 0.2 cm, Lengths 70cm*4, 64cm*4, 42cm*8

4) Wing fabric

Material: Nylon

5.2.2 Prerequisites

1) **Wing:** Various spars of balsa wood are joined together as per requirement with the help of cyanoacrylate adhesive to construct the basic structure of the wing. Nylon fabric is attached to this structure using adhesive to make the complete wings. Fixture to attach wing to the frame is made using mild steel rod by gas welding.
2) **Frame**: Acrylic sheet is cut in required size. Holes of various diameters are drilled as per requirement. To reduce weight, unnecessary material is removed by drilling holes as well as cutting out portion of acrylic.
3) **Electrical Circuit:** Various electrical components such as Arduino, battery, etc. are connected.

5.2.3 Assembly

- Servo motors are attached on either side of the frame with the help of nuts and bolts. Proper positioning of the motors is maintained.
- Wing is attached to the frame using the fixture that was made before.
- Main spar of the wing is directly connected to the shaft of the servo motor.
- Servos are provided power from the electrical circuit.

5.2.4 Final design specifications

Weight: 650g

Wing span: 140 cm

Wing area: 5495 cm^2

Flapping frequency: 2 flaps/sec (without load)

Flapping angle: 45 deg (without load)

5.2.5 Working

Speed and angle of rotation of servo motor is controlled with the help of microcontroller. As a result, a controlled flapping motion is provided to the wing via the motor.

5.2.6 Advantages

- Building of custom gearbox is not required.
- Because of the use of a microcontroller, mechanism is easily programmable, i.e. various parameters like flapping angle and frequency can be varied initially or mid-flight.
- Torque provided is high (12 kg-cm at 7.4V).
- Better lift is provided due to large wing span and wing area.

5.2.7 Disadvantages

Balsa wood spars are weak and get damaged easily.

5.2.8 Result and conclusion

- Due to spars getting damaged repeatedly, proper flapping mid-air cannot be achieved. Hence, better quality material such as carbon fiber is required.
- Lift generated due to huge wing span is much larger than the capacity of the servo motor available. Hence servo motor with greater torque is needed.

Chapter 6

<u>Programming</u>

4.1 Servo Motor Controller Unit Circuit and functions

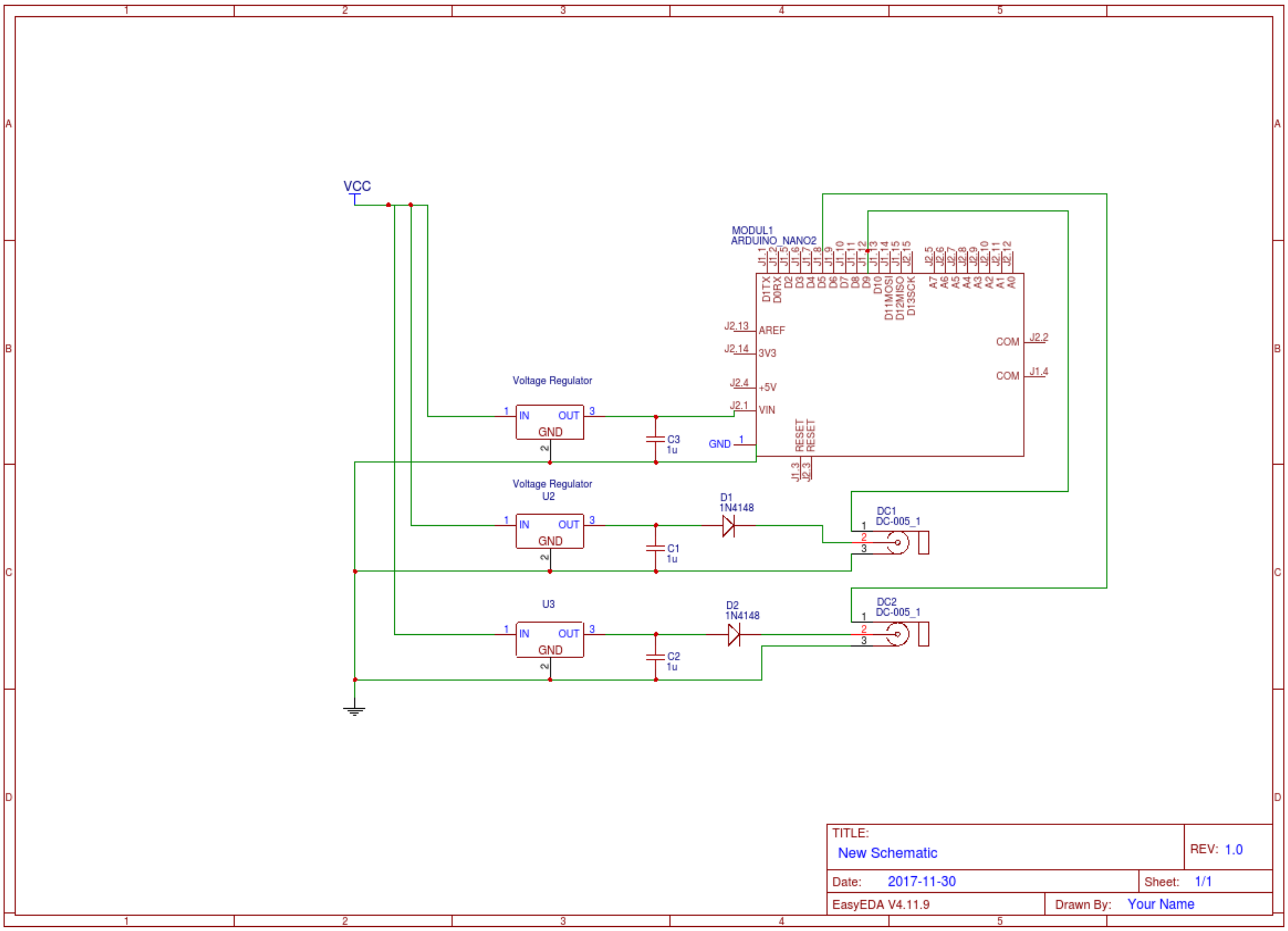


Fig. 15 – Schematic representation of the circuit employed

- Microcontroller Used – Arduino Nano
- Servo Motor – MG996R by TowerPro
- Signal to Servo Motor 1 from D9 Pin in Arduino
- Signal to Servo Motor 2 from D5 Pin in Arduino
- Input Voltage = 7.4 V using Two Li-Ion Battery of 3.4 Voltage Regulators are used to maintain 6V across Servo Motors and Arduino.
- Diodes are used for safety of Microcontroller from Back Emf produced by Motors.
- Capacitors are used to store charge when motors are dragging stall current.

5.2 Program

```
#include <servo.h>
Servo myservoleft;                          // Create Left Servo
Servo myservoright;                        // Create Right Servo

int pos = 0;                                    // variable to store the servo position
int count=0;                               // Counter to store number of flaps per second

void setup() {
 myservoleft.attach(5);               // attaches the left servo on pin 5
 myservoright.attach(9);             // attaches the right servo on pin 9

 Serial.begin(9600);                  // Start serial monitor to monitor number of flaps
}
void loop() {
 myservoleft.write(100);     // Angle given to left servo is from 100 to 150
 myservoright.write(80);      // right servo angle  from ( 180-100) to (180-150)

 delay(160);                                   // Delay of 160 ms is given

 myservoleft.write(150);
 myservoright.write(30);
 delay(160);

 Serial.println(count++);
}
```

- Delays of 160ms are given because motor needs time to relocate its position to given position.
- Motors should be calibrated for different frequency and flapping amplitude or angle of rotation.
- “Count” counts each complete rotation (upstroke and downstroke).

Chapter 7

Results and Conclusion

- Servo mechanism is much better, as it provides better torque, better control and also light weight.
- Lift force primarily depends on wing size and forward speed.
- For wings with large wing span and wing area, lift force is not so dependent on flapping frequency.
- Thrust is dependent on wing frequency.

Chapter 8

Applications and Future Scope

- Ornithopters can be used for scientific research, logistics purpose, agriculture, surveillance purpose, etc.

- Because of its resemblance to birds, it can be used for research on birds and insects and for surveillance purpose.

- Because of its longer flight timing and better stability at gliding, it can be used to collect environmental data such as temperature, pressure, wind speed, humidity, air composition, etc. This data can be very useful for agricultural purpose and environmental research.

Chapter 9

References

1) *The thrust and lift of an ornithopter's membrane wings with simple flapping motion by Che-Shu Lin, Chyanbin Hwu, Wen-Bin Young*

2) *Development of next-generation ornithopter prototypes by John Wood, Daniel Jensen, Peter Leetsma, Christopher Gurrola, Daniel Zheng, Matthew Sparta and Richard Culver*

3) *Ornithopter Type Flapping Wings for Autonomous Micro Air Vehicles by Sutthiphong Srigrarom and Woei-Leong Chan*

4) *Design and Construction of an Autonomous Ornithopter by Zachary John Jackowski*

5) *Effect of Different Design Parameters On Lift, Thrust and Drag of an Ornithopter by M Afzaal Malik, Farooq Ahmad*