Design of Ornithopter Flapping Wing Mechanism

Jithin M P[1], Jude Olivero[2], Naveen M Nair[3], Sarath R[4] ,Vinod Yeldho Baby[5]

[1234]Department of Mechanical Engineering Mar Athanasius College of Engineering, Kerala, India
[5] Assistant Professor, Dept. of Mechanical Engineering, Mar Athanasius College of Engineering, Kerala, India

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Abstract - *In recent years the subject of flying vehicles propelled by flapping wings, also known as ornithopters, has been an area of interest because of its application to micro aerial vehicles (MAVs). An ornithopter is a flying machine which uses flapping wings for propulsion. The flapping produces both lift and thrust. It is by far the flight possible with maximum propulsive efficiency. Due to the close resemblance to insects and birds in both their physical and flight characteristics, ornithopters have been developed for clandestine surveillance as well as to study the aerodynamics of flapping wings. In this project an innovative flapping mechanism resembling a bird is developed. The wing mechanism is such that it produce maximum propulsive efficiency and less drag. Also the ornithopter should be able to carry a considerable amount of payload without affecting its flight characteristics. An attempt to design a tail with high manoeuvring capacity is also tried. There are electronics of the system. Basically the project is a bio mimicry.*

Key Words: *ornithopter, propulsive efficiency, lift, thrust, biomimicry, flapping wing.*

1.INTRODUCTION

Ornithopters a category of flying drones which uses flapping motion of its wings like a bird to propel itself into the air. Traditional ornithopters use a complete membrane wing which flaps its wing with a single degree of freedom. The aircrafts use aerofoil wings to generate lift and engines for thrust. A combination of aerofoils and membrane is the design of bird wing which flaps its wing with multiple folding during upward stroke to decrease the effort in the non-lift producing upward stroke. The flapping mechanism uses a set of gear reduction to achieve the correct frequency of flapping from a high speed motor. During the downward stroke which produces both lift and thrust the wings are fully stretched to displace maximum air beneath the wing to produce a thrust. The bird flight (flapping flight) has the maximum propulsive efficiency compared to any other form of flight (fixed wing flight, rotor flight).

2 DESIGN OF COMPONENTS

Design of the ornithopter consists of four sections.

i. Wing and tail design.
ii. Flapping mechanism.
iii. Gear box.

2.1 Wing and Tail design

The wing is the member that generates lift. The wing is designed by bio mimicry of falcon wing.

A bird wing is divided into three sections.

2.1.1 Primary section

This is the section of wing which has a pure membrane structure and with largest area. The maximum amount of lift and thrust are produced by this section with a vortex formation.

2.1.2 Secondary section

This section is a combination of aerofoil and membrane. The thick aerofoil gradually turns into membrane moving away from the bird body

2.1.3 Tertiary section

This is the section near the bird body. It is an aerofoil section with high camber and small area. This section helps the bird with a small amount of lift while gliding and up stroke

For the aerofoil section of the wing NACA 4412 aerofoil was selected.

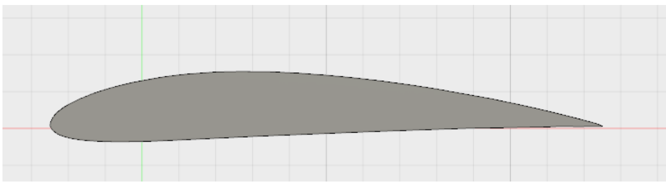

Fig -1: NACA 4412 aerofoil.

Wing dimensions

Width =0.15 m

Length =0.5m

The total length was divided into three sections with lengths 0.34m, 0.13m, 0.08m.

This partition of wings was done according to Fibonacci series and the golden ratio.

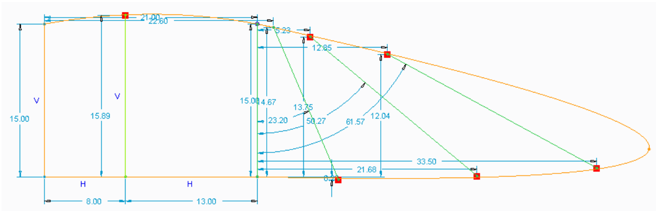

Fig -2: Wing design

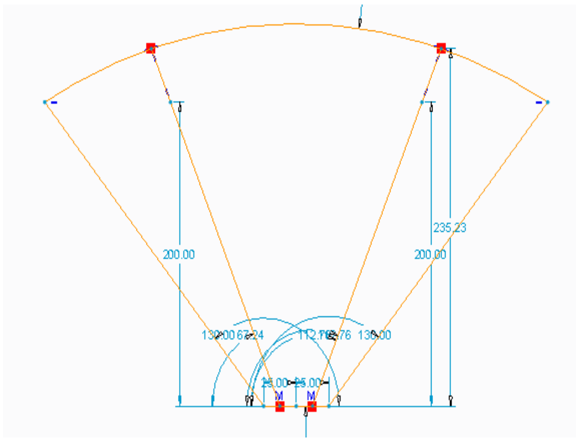

Fig -3: Tail design

2.1 Gear Box

Gear box consists of seven gears. The motor has a maximum speed of 7500 rpm at 9v. So to obtain a maximum flapping frequency of five flaps per second, the gear reduction should be,

5 fps = 5x60 = 300 rpm.
7500/300 = 25

The gear reduction should be 25. Which means while the motor rotates 25 times the main gear rotate once (i.e. the wing will flap one time). This also reduces the torque needed for the motor. Less torque motor means a reduction in motor size and weight.

GEAR NO.	PITCH DIAMETER	NO. OF TEETH	MODULE	QUANTITY
1.	100	100	1	1
2.	40	40	1	1
3.	20	20	1	4
4.	50	50	1	2

Table -1: Gear specification

All the gears have same module which means the all engage correctly and the teeth are same.

The addendum circle diameter of all gears = pitch circle diameter + 2mm.

The gear box design is done in AUTODESK FUSION 360.

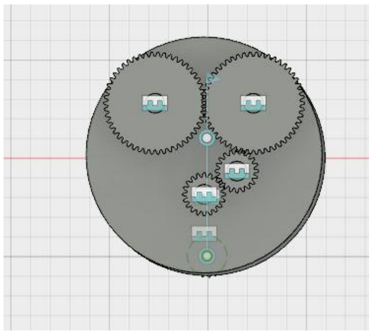

Fig -4: Front View

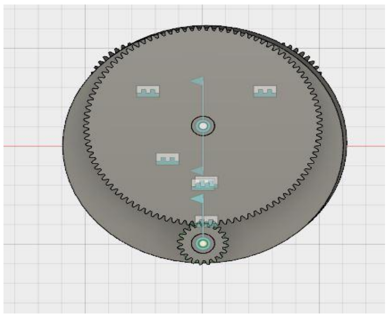

Fig -5: Back View

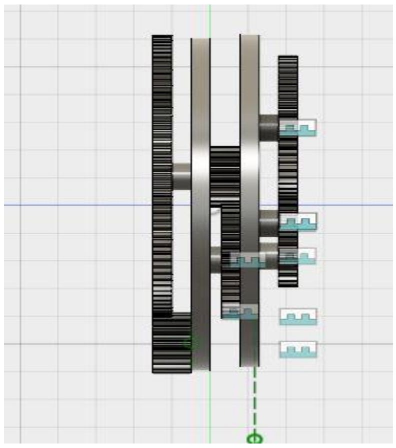

Fig -6: Side View

The gears were assembled on two base plates for supporting them. The shafts used were 10mm nylon shafts with push fit (interference fit).

The equation for gear ratio

$$GR = \frac{numbet\ of\ teeth\ on\ gear\ 2}{number\ of\ teeth\ on\ gear\ 1}$$

GR1 = 100/20 = 5

GR2 = 40/20 = 2

GR3 = 50/20 = 2.5

Total gear reduction GR = GR1 x GR2 x GR3

GR = 5 x 2 x 2.5 = **25**

$$\text{Force at gear periphery} = \frac{torque}{link\ length} = \frac{1.1674}{0.05} = 23.348\ \text{N}$$

Torque required = force x gear radius = 23.348 x 0.025 = 0.5837 Nm

The motor used have design torque of 1 Nm

So the torque available at gear = design torque of motor x gear ratio of final set of gears

Torque = 1 x 2.5 = 2.5 Nm

Which is higher than the required torque.

3.FORCE ON WINGS

Wing loading equation

$$\frac{W}{S} = 0.38 * V^2$$

Weight acting on wings is the total weight of the ornithopter = 1 kg x 9.81 = 9.81 N

Surface area of the wings =0.15 x 1 =0.15 m²

Wing loading = $\frac{W}{S} = \frac{9.81}{0.15} = 65.4$ N/m²

Velocity V = $\sqrt{\frac{65.4}{0.38}} = 13.11$ m/s

Force acting on the wing is the lift.

Lift produced by each section.

For an aerofoil,

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

For a membrane,

$F_L = \frac{1}{2} K_L S_W \alpha \rho V^2$

From α vs. C_L graph, at α = 6°, C_L = 1.2

Wing aspect ratio =$\frac{0.5}{0.15}$=3.333

Velocity of flight (level flight) =15 m/s (approximated from 13.11m/s for designing)

Density of air = 1.225 kg/m³

Air speed = 5 m/s

Section 1

Tertiary section area = 0.13 x 0.15 = 0.0195 m²

F_L = 0.5x1.2x1.225x5²x0.0195 = 0.3583 N

Section 2

Secondary section area = 0.08 x 0.15 = 0.012 m²

F_L = 0.5x1.2x1.225x5²x0.012 = 0.2205 N

Section 3

Primary section area = 0.15 x 0.5 = 0.075 m²

F_L=0.5x3.33x0.075x1.225x15²x $(\frac{\pi}{180} * 6)$ = 3.57 N

Total lift = lift produced by aerofoil + (lift produced by membrane x flapping frequency)

Total upward force = 0.3583+0.2205+ (3.57*5) = 14.8588 N

So there is a net upward force acting on the bird. This force lifts the bird into the air.

3.1. Force on sections

Torque = force x perpendicular distance.

Torque = [3.57x {($\frac{1}{3}$x0.3) +0.21}] + [0.2205x (0.04+0.13)] + [0.3583x$\frac{0.13}{2}$] = 1.1674 Nm

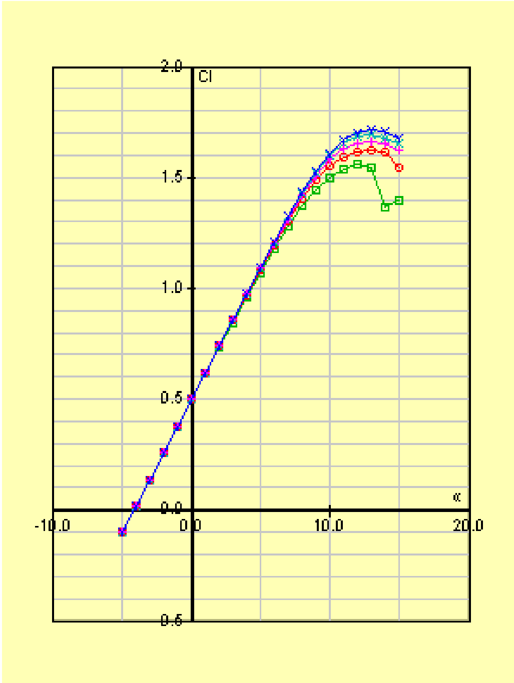

Fig-7 Coefficient of lift vs. Angle of attack (NACA 4412)

4 FLAPPING WING MECHANISM

The mechanism includes a slider crank mechanism and two bell crank mechanisms on each wings. Altogether the wing have a total of three degrees of freedom.

Fig 3.4.1 Catia model of the wing

3. CONCLUSIONS

Ornithopteris a vast area to be explored more deeply. Even though the researches are going on at full potential till now an efficient design which is comparable to a bird in agility and manoeuvrability is not attained. We were able to successfully fabricate a standing model. But an ornithopter which can fly with the systems as per the design done need to be manufactured. The restrictions of making such an ornithopter are the unavailability of correct materials and manufacturing processes. Also the measurements should be very accurate such that a symmetrical flapping is done so that there is no rolling effect

A wing mechanism which incorporates independent wing motion controlled by a sensor can increase agility and sharp steering with the ability to do acrobatics. Also two wing locking positions at fully stretched and fully tucked in will enable gliding and steeping flights.

The most needed characteristics is the capacity to take more payload. This can only be increased by improving the aerodynamics and power. By increasing power together increase the weight which is not good. So better batteries with high power to weight ratios are needed. Improving the material used for membrane will avoid wing tip vortices which induces drag.

We need to study the birds more carefully and deeply to understand the nature's adaptations which was the result of millions of years' evolution to incorporate those in our technologies.

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