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Design and Fabrication of an Articulated Ornithopter

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Abstract - *In the era of developing technologies, the subject of micro sized aerial vehicle, better known as ornithopter, has attracted the attention of a lot of researcher fellows and scientists. These micro sized vehicles are designed so as to closely impersonate the flight and wing motion of an actual bird. This makes it nearly impossible to identify them apart from the live birds in air. With the motive to further study and improve the design of aerial vehicles, we have tried to develop an ornithopter that is proficient in its unique flapping mechanism, resembling the movement of an actual bird. The wing is designed in such a way that it reduces drag by the efficient working of aerofoils attached within the wing structure. The concept of NACA aerofoils was studied and the advantage of one over the other was analyzed using software simulated techniques. Four bar mechanism is used for effective motion transmission from the gear drive to the wings. The report covers all the important aspects required for the development of ornithopter. The design results mentioned thus can be used for making a mechanical replica of a bird.*

Key Words*: *Ornithopter, NACA, micro sized aerial vehicle, drag, Articulated, wings.

1. INTRODUCTION

The bird is a superior and by far one of the most efficient flying objects which can glide as well as fly at one position. In 1924 the mechanism of flapping wings was studied [1]. One of the major problems with the existing drones is their weight lifting capacity and the problem with the remotely controlled aerial planes is they cannot hover at one place. So, by using the concept of flying birds the ornithopters can be made which provides the hovering capacity as that of drones also it offers greater thrust and weight lifting capacity. In short ornithopters combine the features of drones and a remote-controlled plane with greater thrust and hovering stability.

Ornithopter is one type of flapping wing robot or an Unmanned Air Vehicle which uses its tail to give direction s and stabilize itself during the flight. The oscillatory flapping of the wings helps the UAV to generate the high pressure region below its body and gain lift; the wings control the altitude and propulsion of the Ornithopter whereas the tail acts as a steering of the Ornithopter. Bird's wing doesn't only serve the purpose of going up or down but also control the movement in forward and backward direction and allows hovering at one place too. [6]

However, when a single articulated wing is used, it requires 7 Hz of flapping frequency for its flight, but when an articulated wing with primary and secondary wing is used; the bird can achieve lift with 2-3 Hz. When the flight of real bird is studied one can observe that when the birds produce lift, that is, during their down stroke, there is positive aerodynamics. And during the upstroke, the bird's folds its wings, reducing the moment of inertia thus resulting in reduced drag which can be called as negative aerodynamics [2].

With the short span wings the micro aerial vehicles can carry very small or negligible payload, hence to increase the payload carrying capacity of the vehicle, birds having long wings are preferred. But due to long wings there is increase in drag force acting on the wings during its upstroke, thus it is beneficial to use the folded pattern wings which also helps in generating the high pressure region in order to produce the propulsion effect. This type of folded wings cycle consists of four stages [3].

Ornithopter wings that deform aero elastically into an efficient shape are quite effective, as well as inexpensive and simple to construct. To improve the experimental portion of the project, it would be desirable to eliminate the problems caused by wing instability [5].

In 2011 a complex wing articulated ornithopter was manufactured by a German company Festo. They called their ornithopter as Smart bird. Smart bird was equipped with Hall sensors and proximity sensors.

Fig 1: Smart bird

Span	1.8 m
Weight	550 g
Flapping Frequency	2-3 Hz
Flight Speed	4.7 m/s

Table 1: Specifications of Smart bird

2. WING MECHANISM

We have worked on replacements for the rigid flapping wings, which involves greater drag during the upward motion of the wing. Our design is inspired and originated from the Seagull wings, which bionically folds its wings during upward stroke. Firstly, the CAD model is constructed in SolidWorks software. Natural fliers are the simplest supply of inspiration for creating associate UAV with desired characteristics. Within the early years, terribly massive flap wing robots were explored, sadly, rarely succeed. Recently, promoted by the stress in each military and civil usage, tiny scale flap fly robots are sky-high involved. Several thought prototypes were analytically, through an experiment and computationally studied, being galvanized by completely different nature flyer like dragonflies, butterflies, hawk, moths, bats, and flies.

The flapping cycle of the wing consists of four stages:

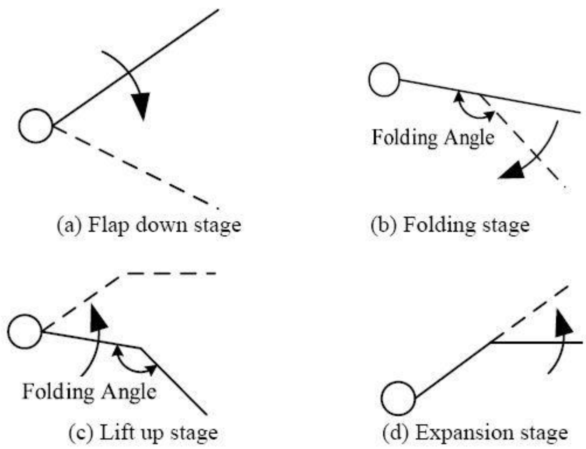


Fig 2: Stages of Wings Flapping cycle

1) Slam stage (Down stroke): The wing keeps spreading to the utmost throughout the full stage, and there's no obvious comparatively folding angle between the inner and outer components of the wing. This stage contributes within the total elevate created by the wing. During this stage the wing force acts within the upward direction on the lower surface of the wing.

2) Folding stage: once the inner half reaches the lowest position and takes a disruption, the outer half continues moving a little while to create the sunburst angle between the 2 components. Therefore that the whole wing shrinks to the minimum. during this stage as a result of folding of the outer half a aggressive region is formed below the body a part of the ornithopter, this high contributes in further quantity of elevate as compared to rigid wing ornithopter.

3) Elevate up stage (upstroke): The inner and outer wings keep the relative position unchanged, and also the whole wing rises up till the very best position. Throughout the increase the two components of the wings stay in the sunburst position that reduces the performing drag during the lifting of the wings.

4) Growth stage: once the inner half rises to the highest position and takes a disruption, the outer half keeps rising quickly till the wing expands to its most. Then the next flap cycle begins.

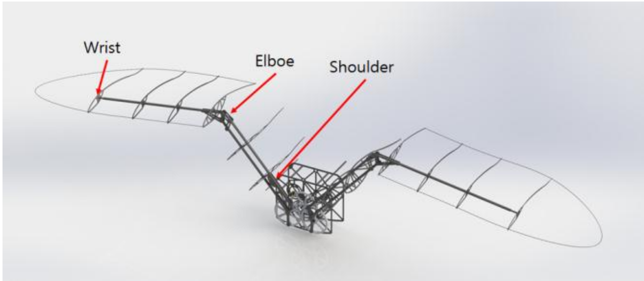


Fig 3: Foldable wings

3. KINEMATIC ANALYSIS

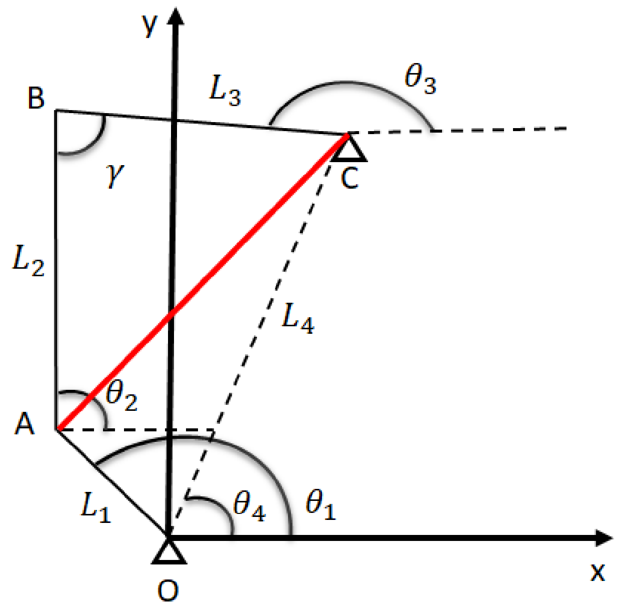


Fig 3: Diagram of inner flapping wing mechanism.

In the figure is the wing mechanism consisting of four linkages forming a crank rocker mechanism for the articulated wing. (L1=Crank, L2= Coupler, L3= Rocker, L4= Ground).

In this paper, the span length is 1.8m, $\theta 3$ is the Inner flapping angle, the design condition of this paper is set to L1 = 60mm, L2 = 78 mm, L3 = 86 mm, L4=116.3 mm. 4 = 64.53 which is the input value.

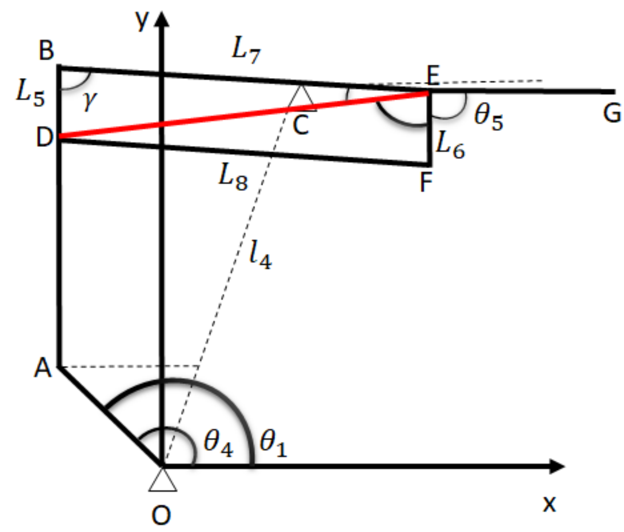


Fig 4: Diagram of mechanism in Kinematics.

DE is f(γ) and γ is f(AC) and AC is function of the input value. We have set L5 = 25.5mm, L6 = 25.5mm, L7 =249mm, L8 = 249mm and θ5 = 71°.

4. DRIVE MECHANISM

	Main gear	Reduction gear	Motor gear
Teeth	72	60	12
Module	1	1	1
Diameter	72	60	12
Width	6	6	6

Table 2: Gear Information

The drive mechanism is attributed with the dual gear crank design. In this design, each of the gear controls the wing hinges separately. The pinion wheel connected to the motor drives both the secondary gears. One of the design features the secondary gears rotating in the same sense with respect to one another. As against this in the other design, one secondary gear is driven by the pinion and it rotates the other in return. In this scenario both the secondary gears will rotate in opposite sense to one another. The later design is hassle free to put into use. Moreover, it has also proven to reduce the misalignment. There are variations in the design of the tail according to the purpose it has to satisfy. Some designs use it for the sole purpose of stability of the ornithopter during flights whereas it is primarily used for both control and stability. Tilting the tail up or down forces the nose to pitch down or pitch down respectively thus helping to stabilize the bird [7].

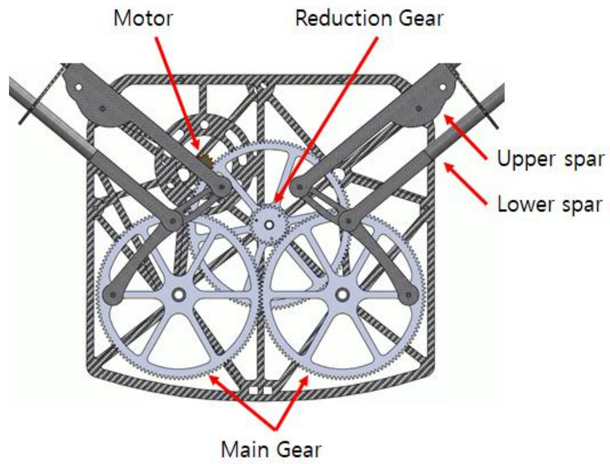


Fig 5: Drive Mechanism

All the gear drive calculations are based on the assumption of 5 Hz of flapping frequency and 900KV BLDC motor.

5. AIRFOIL IN THE WINGS

While determining the type of airfoil required for a definite purpose, various parameters like effective angle of attack, plunge amplitude, formation of leading-edge vortices should be considered. The airfoils should be capable of generating optimum amount of thrust. For our purpose during the flapping period of wings these thrust producing airfoils should be at large effective angle of attack. Also, the lesser plunge amplitude of the airfoils helps in decreasing the vortices production at the leading edges which results in increasing the propulsive efficiency of the airfoils [4].

For any aircraft airfoils plays an important role. It also determines amount of weight that can be lifted by anybody and also the drag produced by that body. The flow behaviour around the airfoil body can be investigated by the analysis of airfoils.

The NACA stands for National Advisory Committee for Aeronautics. The airfoils are designated by various series numbers.

For our purpose we have considered NACA four-digit airfoil series. The four digits designated as per follows:

1. First digit of the series stands for maximum camber as percentage of chord.

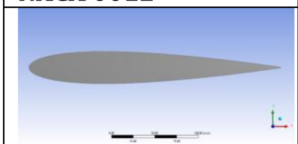
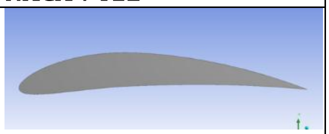
2. Second digit of the series stands for the distance of maximum camber from the airfoil leading edge in tens of percent of the chord.

3. Last two digits stands for the maximum thickness of airfoils as percent of the chord.

For our purpose, we have considered two NACA airfoils series NACA0012 and NACA7412

AIRFOIL ANALYSIS:

Firstly, the airfoil curve is created by referring the data provided on the standard website. After this 3D model is created using 3D modeling software and the analysis is done in Ansys workbench. For the fine analysis purpose fine meshing is selected also, velocity of air at the inlet of airfoil is considered as 5-8 m/s. Angle of attack for the airfoils kept as per the standard (6º). The lift will be the upward force acting on the internal surface (the coordinates X0 Y1 Z0 will give the lift force). The drag will be the resisting force produced by the air on the airfoil (the coordinates X1 Y0 Z0 will give the drag force) \

NACA 0012	NACA 7412
	
Drag – 0.7286 N	Drag – 1.1667 N
Lift – 0.0014 N	Lift – 0.1557 N

After the analysis of NACA7412 and NACA0012, it is observed that the lift produced by the NACA7412 airfoil is more than the lift produced by the NACA0012 airfoil series.

By the Bernoulli's principle, as the velocity increases there is decrease in pressure. Hence, the pressure on the top of the airfoil surface will be always greater than the pressure on the bottom of the airfoil surface.

The number of airfoils on the wing also decides various factors such as trapping of air between the airfoils however the smaller number of airfoil results in more trapping of air in vacant space also the greater number of airfoils results in increasing the weight of the ornithopter. Therefore, total 18 airfoils are mounted over the 1.8 meters wing span.

6. DESIGN AND FABRICATION

The articulated winds are designed with airfoils mounted on them with the combined gear drive mechanism mounted in a chassis structure. All the design is done in SolidWorks. The Gears are 3D printed and the airfoils are laser cut in Balsa wood.

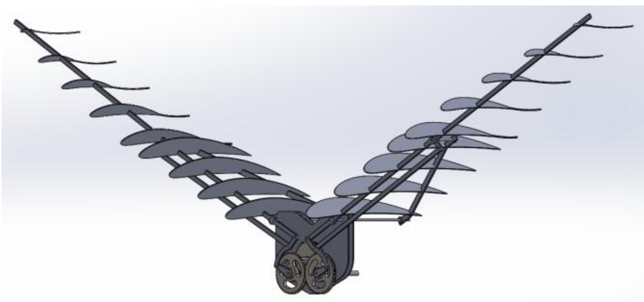


Fig 6: Final Assembly

7. DESIGN ACHIEVEMENTS

1) The use self-fabricated sheets of carbon fiber which are light weight and high in strength have made our design reliable.

2) The use carbon fiber strength has made our design reliable.

3) The design of NACA 7412 airfoil for the articulated wings delivers the better lift and propulsion efficiency.

4) Articulated wings design which requires the less flapping frequency have made our design superior than the other designs having flapping wings structure.

5) Design of gear drive maintains the symmetry about the longitudinal axis which helps to keep the centre of gravity near the middle axis.

8. CONCLUSIONS

From the research regarding the various designs of flapping wings and articulated wings Ornithopter we can conclude that:

1) To ameliorate the performance of Ornithopter the important factors which need to be focused are propulsion efficiency and lift.

2) The flexibility of outer part of articulated wings renders the better propulsion efficiency and the inner part provides the lift.

3) The long wingspan mitigates the high flapping frequency requirement.

4) From the Bernoulli's principle the profile of NACA 7412 produces the higher-pressure difference around the airfoil than the symmetric nature of NACA 0012.

5) The use of motor with same power generates the higher lift with NACA 7412 than the NACA 0012.

9. ACKNOWLEDGEMENT

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