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Conceptual Development of Flapping Wing for Unmanned Aerial Vehicles: Technical Note

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ABSTRACT:

From 1940's to till now the Un-manned aerial vehicles (UAVs) technology has been developed and the birds like UAVs are actively used for spying mission to attack enemies. For example, "Smart Bird" is discovered by FESTO in which the seagull is taken as a concept. The battery consumption is more on these UAVs due to their complicated flapping mechanism. This project deals with an UAV (ornithopter) with morphed wing, in which the wing can be foldable to increase the gliding speed. By using such type of wings, endurance and range can be increased. A laboratory scale ornithopter with flapping wing mechanism is fabricated and tested. The flight speed of almost 45mph can be achieved. This mechanism reduces the battery consumption, for e.g. for 8V input, 4 flaps per second is demonstrated by test. UAV has the ability to attack enemy territory without being identified by the RADAR. Moreover, it can be used to drop bombs from high altitude with precision by using high resolution cameras. To overcome this difficulty, the ornithopter with morphing and flapping mechanism concept is considered in this project.

KEYWORDS:

Ornithopter; Flapping mechanism; Unmanned aerial vehicle; Laboratory scale test; Flapping frequency

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1. Introduction

Unmanned Aerial Vehicles (UAVs) have the potential to revolutionize the sensing and information gathering capabilities in areas such as environmental monitoring and homeland security. Numerous vehicle concepts, including fixed wing, rotary wing and flapping wing, have been proposed. As the size of a vehicle becomes smaller than a few centimetres, fixed wing designs encounter fundamental challenges in lift generation and flight control. Since UAVs are of light weight and fly at low speeds, they are sensitive to wind gust. Furthermore, their wing structures are often flexible and tend to deform during flight. Consequently, the fluid and structural dynamics of these flyers are closely linked to each other. Because of the common characteristics shared by UAVs and biological birds, the aerospace and biological science communities are now actively communicating and collaborating. Much can be shared between researchers with different training and background including biological insight, mathematical models, physical interpretation, experimental techniques and design [1].

Several researchers [2-5] have developed mechanisms to realize the flapping motion and used these mechanisms in micro aerial vehicles (MAVs) to demonstrate that these mechanisms can be used to achieve flapping wing flight. Madangopal et al [2-3] developed a flapping wing mechanism inspired by insect and bird flight. They presented the kinematic and the rigid-body dynamics models of the mechanism and proposed an aerodynamic model of the for the wings' motion. Galinski and Zbikowski [4] examined the material challenges for a flapping wing mechanism based on the insect hovering kinematics. They concentrated on building a robust test rig design rather than a lightweight mechanism optimized for flight. Conn et al [5] presented a biomimetic analysis of an insect flight and proposed biomimetic guidelines for mechanism simplification. A novel parallel crank-rocker MAV flapping mechanism was chosen to replicate insect wing kinematics. Zdunich et al [6] developed and tested the Mentor flapping wing MAV. They described the experimental development of the wing design and its unsteady-air foil analysis. They described two successfully tested flying prototypes and analysed their flight tests results. Wood et al [7] have worked on implementing gliding concepts inspired by insects on the centimetre scale.

There are numerous factors such as the physical properties of air (e.g., density, viscosity) the physical characteristics of the wing, the flapping motion (e.g., frequency of flapping, degrees of freedom), and the forward motion of the flapping wing (e.g., Reynolds number) that can affect lift and thrust. For a given flapping wing design, since the lift and thrust are coupled, these factors can simultaneously affect these forces. For example, higher the air density and the frequency of the flapping motion leads to greater lift and thrust. Fig. 1 shows an example ornithopter.

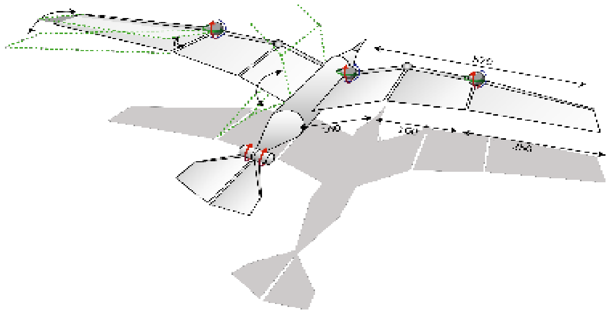

Fig. 1: Overall view of ornithopter

If the flapping motion becomes too vigorous, the compliance of a wing or air turbulence can cause instabilities that reduce lift and thrust. The level of lift and thrust that is capable of being generated by the flapping wing at a given flapping frequency will affect the amount of payload that the object can carry. Therefore, it is necessary to assess the dependence of the lift and thrust on wing shape and area in order to design a MAV that generates maximum thrust and lift with a minimum amount of weight [8]. In order to create an effective ornithopter, its wings have to generate enough power to take off the ground and travel through the air. In this paper, efficient flapping of the wing is characterized by pitching angles, lagging, plunging displacements by approximately 90°. More power is required on the down stroke than on the up stroke. If the wing on the ornithopter was not flexible and flapped at the same angle while moving up and down, it would act like a huge bird moving in two dimensions, not producing lift or thrust.

Birds' wings have four basic patterns of movement - flutter, reverse, swing, and folding during the normal course of flat flight as shown in Fig. 2. Spur gears teeth meet suddenly, at a line of contact across their entire width. These causes stress and noise. As a result, spur gears make a characteristics whine at high speeds and cannot take us much torque as helical gears.

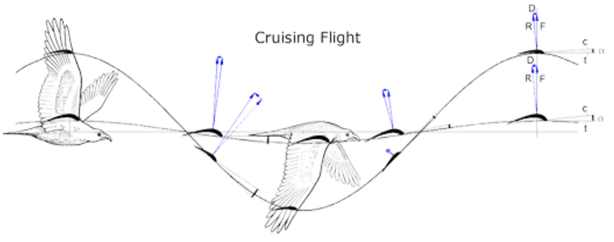

Fig. 2: Principle of flapping wing UAV flight

2. Design and fabrication

For the design consideration, the UAV dimensions are taken from a real bird in the range of 1:2 ratio for the dimensions the wing, tail and the other components. For the flapping of the ornithopter the gears play major role in the design consideration. Gear and pinion is made up from cast iron with the help of hand machine for high finishing. Three gears are being used to reduce vibrations and maintain 1:30 gear reduction ratio as shown in Fig. 3. The crank forms a link between the driving and the driven parts. The crank was initially made out from aluminium alloy then changed to carbon fibre due to low strength. The assembly of main gear box is shown in Fig. 4.

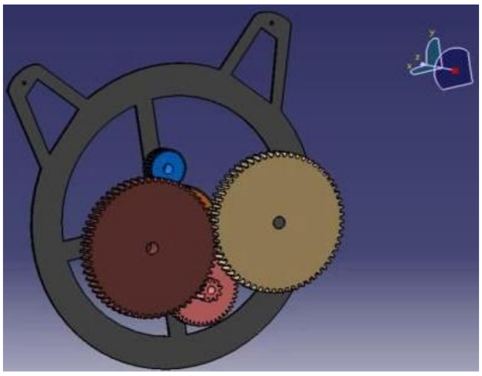

Fig. 3: Gear design

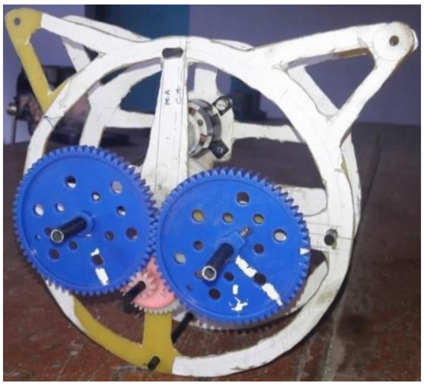

Fig. 4: Main gear box structure

Semi-elliptical wing design has been chosen for the ornithopter to give good performance and produce more lift. In this wing as shown in Fig. 5, the front triangle part is the lift generating area and flexible part of the wing which is for the forward motion of the ornithopter. Fuselage forms a platform for mounting all the necessary components. Main body is made up from 2mm thickness carbon fibre rod for the longerons. Carbon fibre is mainly selected for its higher strength to weight ratio when compared with balsa wood. Wing hinge is made up from carbon hollow tube and joined with cast iron screw to the fuselage. Carbon fibre rod is used for the tail and covered by the miler sheet. The directional controller of the ornithopter is made up from 2mm glass fibre.

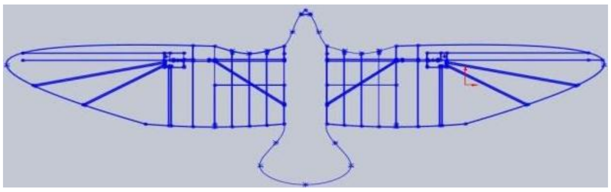

Fig. 5: Internal frame and components design

Fig. 6: Air foil sections cut through glass fibre

The air foils are chosen through thickness to chord ratio as shown in Fig. 6. These air foils are used in order to produce considerable amount of lift during gliding condition, after the ornithopter reaches certain altitude the wing will be stable and these air foils are used to glide the ornithopter for a long-time period. Wing spar is made from 2mm carbon rod. Additional spar has been used for mechanism testing. Crank rocker mechanism using spur gears is fixed at the front part of the ornithopter. This mechanism converts the rotary motion of driving unit to linear motion. Details of wing assembly and over all assembly of all components are shown in Fig. 7 and Fig. 8 respectively.

Fig. 7: Wing assembly

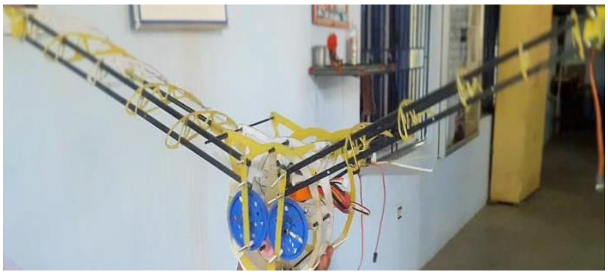

Fig. 8: Overall assembly of internal structure

From the testing of flapping mechanism, the maximum attained flapping frequency is 4 flaps per second. This flapping frequency is required to produce sufficient amount of thrust to make an ornithopter to glide as well as to propel the UAV forward. From the known applied volt from the battery, the flapping frequency produced by the motor with respect to gear ratio and rotation can be established using Fig. 9.

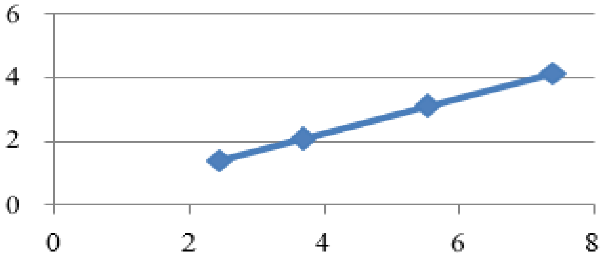

Fig. 9: Flaps per second (frequency) vs. Applied voltage (V)

3. Conclusion

The goal of this project is to develop an ornithopter that is capable of hovering, gliding and morphing. The fabricated ornithopter was tested at laboratory scale. For the maximum applied voltage of 8V from the battery, the flapping wing mechanism has achieved 4 flaps per second. Future work will be focussed on the detailed design of an ornithopter wing and tail through CAE.

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