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Design & Development of Bi-Plane MAV

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Abstract: The research of micro aerial vehicles (MAVs) is a new field of low-Reynolds-number flow, which attracts much attention in the advanced aeronautical area. Micro air vehicles propelled by flapping wings are gaining interest for certain applications because flapping can provide more agility and manoeuvrability at low speeds. Flapping wings must deform in certain shapes to produce maximum lift and thrust. In the paper, we discuss an approach we used to design flapping wing Micro Air Vehicles (MAV), which replicating the flying patterns of birds. The development of MAV is complicated and it involves light weight design, power transmission design, flight controls, low Reynolds number flight, energy supply etc. The main objective of this work is to build an ornithopter with very less wing loading which can be used for surveillance purposes. The weight factor plays an important role and wing loading needs to be as low as possible. An experimental approach adopting trials and error methods was used to fabrication. Finally four wing MAV is designed for a wingspan of 28cm, total length of 175cm, weight of 14g and it involved a tail rotor for controlling the yawing movements. The prototype, then manufactured, assembled, performed several tests and achieved commendable flight.

Keywords: Flapping wing Micro Air Vehicle (MAV), tail rotor, Ornithopter, wing loading etc.

I. INTRODUCTION

In recent years the development and research done on flapping wing Unmanned Micro Air Vehicle, have a wide range of applications like military, surveillance, search-and rescue, etc. But the development of flapping wing MAV has been lagging, due to the complexity of the design and the unsteady aerodynamic forces of flapping wing. Current research interest on developing miniature aerial vehicles (AVs) modelled on the aerodynamics of birds and insects. Many researchers launched AVs demonstrating forward flights have been developed like the Microbat [1] and Delfly [2]. Flapping wing aerial vehicles have substantial advantages over traditional vehicles: low noise signature, high efficiency at smaller scales, low Reynolds's number, survivable and robust. The analysis of flapping wing motions of natural fliers is crucial as they provide clues to design better flying machines at smaller scales [3]. The flapping patterns of flying creatures consist of a flap or stroke and rotation or twisting of the wing which can be divided into two types of flapping wing mechanisms: active and passive. An active mechanism is one in which wing rotation is generated by actively rotating the wing to generate an angle of attack during each stroke [3, 4, 5, 6, 7, 8]. A passive mechanism uses aerodynamic drag and the flexibility of the wing to generate wing rotation [1, 2, 3, 9]. MAV can be categories into: Ornithopter (bird-like flapping) and Entomopters (insect-like flapping).

The ornithopter is capable of only flying forward where as the entomopters is able to fly forward and hover as well. In case of birds, it is found that their wing roots and portions of the inner wing behaves like a fixed wing producing most of the lift for flight while the wingtips do the maximum work by flapping. In some insects, vortex is a head before the upstroke begins. Another boost in lift occurs at the beginning of the upstroke as the wing passes through the wake of the downstroke [10].

Most insects clap and fling their wings that are rigid for light that generates more lift than conventional beating wings. It can be seen being used in nature by sparrows and some species of fly. Mechanically the clap and fling works by rapidly bringing two wings together beginning with the leading edge. The leading edges touch and flexible wings will follow in a phenomenon known as feathering. As the wings come together air is pushed out the back generating thrust, which when angled properly will create lift. Once the wings are together they immediately begin to peel apart allowing air to rush in from the front. This suction also creates thrust, pulling the wings forward. From an outside perspective the air is being circulated around the wings and creates lift. The wing is rapidly moving though air resulting in unsteady flow and vortices forming around the leading edge. These vortices will interact in ways not yet understood with the vortices coming off the edge of the wing creating additional lift. All of these phenomenons together are illustrated in Figure 1.

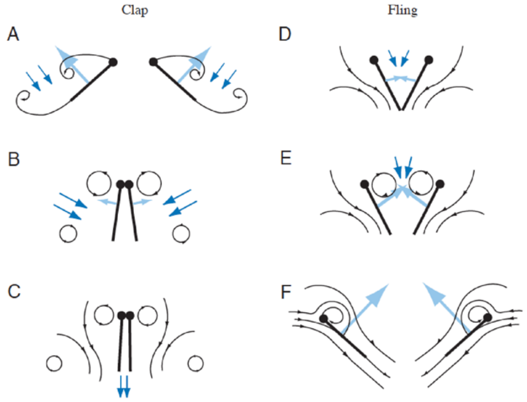

Fig. 1: Clap and Fling Method

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Motivated from this study, group decided to develop MAV of clap and fling type wing flapping, which is able to generate required lift than the conventional flapping and group designed a double crank flapping mechanism. This is simplified variant of the complex biological wing. The main objective of this work is to build a small flapping wing vehicle that possesses a wingspan of approximately 28cm and weighs approximately 13g. This vehicle should be capable of vertical takeoff and landing (VTOL) as well as high manoeuvrability for indoor and outdoor environments.

Project Goals and Requirements
The main goal was to design, examine and build a flapping winged MAV suitable to fly inside as well as outdoor. The project requirements were:

1. Wingspan: 28cm.
2. Weight: 14 grams (including payload).
3. Flight time: 10 minutes.
4. Non autonomous flight–remote control capability.

Objectives

- Generate lift with a flapping wing
- Design software/hardware remote control system that allows for flight control
- Create forward and hovering flight

II. MARKET SURVEY

After defining our goals, a market survey was made, to examine different solutions and methods to implement a MAV which uses its wings to flap. The most suitable MAV found are summarized in the following table 1:

TABLE 1: MARKET SURVEY

Name	**Origin**	**Wing configuration**	**Weight [gr]**	**Wingspan [cm]**	**Flight time [min]**	**Notes**
Delfly II	Delft Univ.	X-Wing	15	25	15 – straight flight 8 - hover	Camera as a payload, Transverse shaft flapping mechanism
Microbat(4th model)	UCLA + AeroVironment	V-Wing	14	22.9	~25 (no hover capabilities)	No payload, Staggered crank flapping mechanism
Mentor	SRI + TorontoUni	X-Wing	55	30	15-hover	exceeds DARPA's definitions for MAV
NPS 1 lithium 13.427	Naval PostGraduateSchool(NP)	2 front –fixed. 2 rear - flap	13.4	27	>3	Different concept: front wings are fixed, and there are wings flap – improves the dynamic stability.

III.DESIGN CONCEPT

The flapping wing MAV would be based on an ornithopter design. The main basic design process starts with the sizing of small flapping wing vehicle capable of vertical takeoff and landing, hover, and horizontal flight. Design of mimicking a two-wing bird or insect would be difficult and unreasonable, for these animals move in a very complex manner. Through more research and the discovery of the clap-and-fling method of flight, the group decided upon a four-wing vehicle with tail surfaces to provide stability and control. This would be easier to model and manufacture than the motion required for a two-wing vehicle to take flight. After concluding the flapping mechanism, the next step is to choose components and materials required in the design. Several electronic components also involved in the design: a battery, a motor, speed controller, magnetic actuator, a receiver and a transmitter. These components must power the MAV, flap the wings and control the tail surface. Detailed description of design process is reflecting in the flow chart shown 2.

Flapping Mechanism: The flapping wing mechanism function is to converts motor's rotary motion into flapping motion. It is the most important component of the MAV thus much researchers done work on many different designs available. Based on that information, group decided to build four winged MAV means the maximum amplitude between two wings. The method involves two counter-rotating gears, spinning perpendicular to the forward movement of the MAV (with their axels parallel). Mechanically, this design is more simple and easier to construct, and due to the counter-rotation, the gyroscopic forces would be minimized. Here, the motor drives the rotating right crank (RC), which in turn drives the left crank (LC).

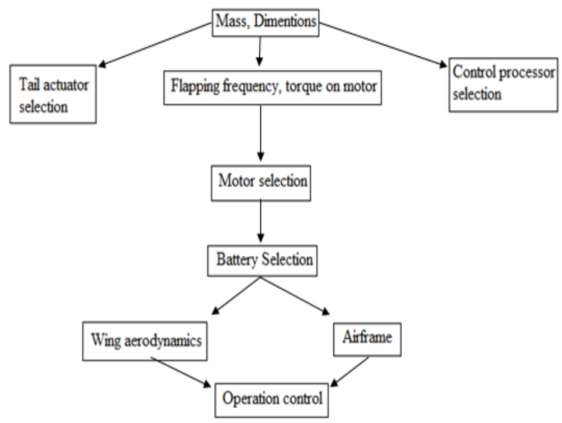

Fig2. Flow chart of Design Process

Both cranks have connecting to connecting rods attached to it and the other ends of the connecting rods are attached to the wings. As the cranks goes around, the connecting rods pushes the wings up and down as shown in the Figure 3.

A. Gear design: care should be taken while selecting gear mechanism; from our motor tests we discovered that a drive train ratio of 1:19 would be desirable.

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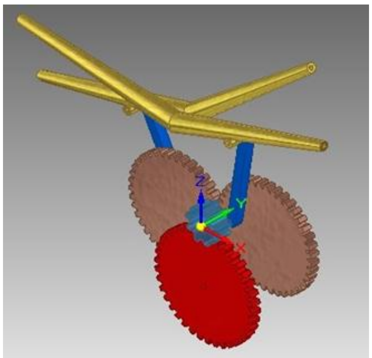

Fig 3 Wing mechanism

This would give us an acceptable drive train assembly. The motor has 13300rpm but model is designed for 10Hz flapping frequency. For 10Hz frequency 700 rpm is enough. This needs reduction of 1:19 which achieved in two steps.

B. Motor & Battery
Generally, RPM of the motor is proportional to the voltage input. Since an ornithopter would not be operating at high RPMs a high voltage was unnecessary. Brushless DC motor would be most appropriate for this project and it has several advantages over brushed motors. They have more torque per weight, and more torque per watt, making them more efficient. Hence a brushless combination which has lesser rpm but better torque and weighing 2.8 g was used for cranking the mechanism. The ornithopter model uses a 3.7 V 55mAh lithium-Polymer battery with 1.96 grms for its operation. Though the capacity of the battery is low, it has enough charge to demonstrate flight.

C**.** Actuators and Receiver
One magnetic actuator is used at the control surface of the tail and weighing 1.23 gr. Micro9 3 Channel, a range of 30 meters, and a weight of 0.95g Receiver as a compatible receiver option. The Micro9 is designed to work specifically with the selected actuators, simplifying installation and control. Microprocessor is used to run the MAV autonomously.

D. Body
The shape of the body should be simple and lightweight. There is a solid carbon fiber rod of 1mm dia and 75 mm long piece running from the tail to the nose, which gives support to mount the drive train, hinge and tail is supported at back end of body. The length of the body was designed to match the wing span, thus keeping the MAV as small as possible while making control feasible as well.

E. Wings and Tail
The wings of the flapping wing MAV are one of the most crucial components as it is used for creating lift, drag and thrust which are prerequisites for any avian flight. Flapping wings are generally constructed using stiff, lightweight rods as structural materials. Design involving four wings, and it is crucial for each wing to be as lightweight as possible. Thin polyester films are used for wings, and lightweight spars to provide support and allow for the clap and fling effect. The group also researched multiple designs for the tail structure. Tail still consists of two elevators and a rudder; however the entirety of each surface is a movable control surface. This design is simpler to manufacture than attaching elevators onto the horizontal tail, and is expected to allow for more control during flight. The tail redesign, including the control disks and actuators, is shown in Figure 4.

Fig. 4 Magnetic actuator

F. Hinge
A hinge is necessary to hold the four wings together and allow a flapping motion that brings the leading edges together. Hinge would withstand the rapid movement without failure, and because the hinge is so small, would not add a considerable amount of weight to the MAV. Thus Fiber made hinge is used.
Detailed specification

- Wing span= 28cm
- Wing area= 133 cm2
- Wing loading= 0.105 g/mm2
- Flapping amplitude=400
- Wing flapping frequency= 24Hz
- Gear ratio=1:19

IV. FABRICATION

The wing span of the MAV is 28 cm and its surface is covered with a thin polyester (PET) film with a thickness of 25 µm. The PET film is glued directly to the spar and rib rods with a double-sized adhesive tape. It was found that this simple approach is sufficiently strong enough to withstand the highest frequency (24 Hz) of flapping motion without encountering any difficulty. To provide additional strength to the wings, a trapezoid tape was layered along the leading edge to enhance the stiffness of the film near the area. In the current design, the motor was power by a commercial poly-lithium battery of 30 or 55mAh. The tail structures were made up of EPO foam and it is fixed at back end of the body and they were chamfered at the corners to keep them from failing under unforeseen circumstances. Tail is fitted with rudder and it is operated by magnetic actuators. The total weight of the MAV including battery, receiver and microcontroller is 14 gram. Table 1 shows the breakdown of the weight for each component.

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Table 1. Breakdown of the weight for each component of the Mav.

S.No	Item	Weight in grams
1	3-channel receiver	0.95
2	Microprocessor	2.2
3	Magnetic Actuator	1.23
4	Motor	2.8
5	Frame	0.24
6	Battery	1.96
7	Tail	0.3
8	Wings	1.05
9	Drive links	0.25
10	Tape, Glue, carbon frame	1
11	Thermocol body	0.8
Total weight		**12.78 grm**

V. FINAL ASSEMBLY

After manufacturing the individual parts, assembly was rather straightforward. The hinge, gears, drive bars, and control discs could all be fastened to the body with small metal brads. Super glue is very effective in attaching the spars to the hinge, as well as the actuators to the mounts and subsequently, the mounts to the body. Fig 5 shows the complete assembly.

VI. EXPERIMENTAL LAYOUT AND RESULTS

Some experiments were performed to optimize the flapping and wing design of MAV. These are described here.

Wing Size: Several design stages were involved in designing the wing. The first set of triangular wings produced almost no thrust after we tried flapping them for the first time. Then the wing frame was redesigned. Further experiments were performed using this set of wings as they produced much more thrust.

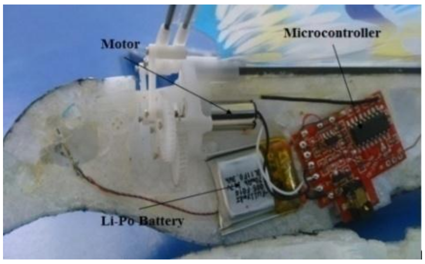

Fig. 5 Complete assembly of MAV

Amplitude: The throw of the wing is decided by the distance between the holes drilled in the FRP pushrod. Several experiments were performed with different amplitude to determine the advantages of each one of them. It was deduced that the small amplitude provided fast flaps, but not sufficient thrust whereas the large amplitude provided slower but higher thrust flaps. Moreover with larger amplitude more jerky flapping motion is associated. Hence it was decided to settle on amplitude approximately in the middle of the range in which experiments were performed.

VII. FLIGHT TEST

After assembling all the components, includes the transmission model, flapping wings, fuselage, tail, receiver, battery, and actuators, the total weight is 14 grams, a span of 28 cm. Developed light weight MAV enables it to have a more outstanding flight performance than other MAVs. The flapping MAV demonstrated the ability to perform acrobatic moves, such as dashing, rapid turning, taking off and landing, looping and hovering. The flapping MAV demonstrated the ability to perform simple acrobatic maneuver and it has also flown successfully outdoor with a gust wind of 5 mph.

VIII. CONCLUSION

The objectives which were to design, build and fly a flapping wing MAV, was all met. The FWAV developed is capable of producing sufficient lift and thrust with onboard power supply and control electronics. The vehicle is operated by a single magnetic actuator. It generates flapping pattern similar to that of birds. It was found that flapping wings provide more lift per unit span and it can fly up to 20-30 meter height for about 10min. MAV has also flown successfully indoor as well as outdoor environment.

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