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Robotic Bird

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Abstract

Now-a-days robots have taken its remarkable position in the development of a nation. Robot has changed the structure of society and made available different devices for safer and comfortable condition. Various robots are developed to perform varieties of task. Researchers are taking inspiration from the nature and try to develop novel robots. Biological inspired robotics has emerged as an important area within the field of robotics. People dreamt to fly like a bird since the earliest civilizations. The study of robotic bird is the race to overcome natural flight through mechanical means. Numerous devices have been developed with an objective to achieve optimum natural flight capabilities since the concept of ornithopters or Flapping Aerial Vehicles (FAVs) flourished. This paper aims at discussion and comparison between various aspects of flying robot. The comparative analysis is done in the fields of mechanism employed, designing techniques, materials, actuators, power source used, transmission mechanism, type of tails, controllers as well as the mainframe. Relative studies have concluded to a number a limitations or drawbacks that are currently observed in FAVs, which has been put forward in the paper. A number of already developed FAVs were studied in order to present the following premise serving as a common platform.
Keyword- Flapping Aerial Vehcle, Micro Aerial Vehicle, Ornithopter, Robotic-Bird, Samrt-Bird, Unmanned Aerial Vehicle

I. Introduction

Nature has always inspired and fascinated humans. Humans try to imitate the ways and functioning of nature to achieve perfection. People dreamt to fly like a bird since the earliest civilizations. The study of FAVs is the race to overcome natural flight through mechanical means. However the efficiency, maneuverability, flight endurance limit, as well as the aerodynamic stability of a natural flyer is almost impossible to achieve. An Ornithopter or a FAV is a mechanical device that uses its ability to flap wings as a locomotive agent. These ornithopters can be powered by a number of resources such as rubber band, IC engine, or may be electric powered. A complete history of the ornithopters over the years can be obtained in literature [1]. Today, the ornithopters are being developed by humans having the "perfect flight" of a bird in mind, as a touchstone. Also, more development is observed in the field of flapping vehicles as compared to fixed-wing or rotary type, as the former being more aerodynamically stable, efficient at a smaller scale than the latter [2,3]. Thus, the inability to pull off the desired natural flight as birds in the FAVs can be argued in terms of its limitations. In spite of the persisting drawbacks, the most common aerial vehicles used today are fixed wing or rotary type, in which the required thrust is produced by use of propellers and the lift generated by the fixed wings is highly dependent on the free-stream velocity [4].

This Unmanned Aerial Vehicles (UAVs) provide with a wide range of application in the field of military surveillances, local inspection of a particular area, communication network links, local food deliveries, first-aid and medicines as well, in the remote or disaster-struck areas of the world. UAV applications were mainly due to rapid response or due to the harmful environment in the surveillance area. The possibilities of the use of UAVs today and in the future have been briefly discussed by J.Everaerts [5]. The use of UAV systems from the year 2004 to 2007 follows an increasing trend, be it for civil, military, both or research purposes. However, UAVs are not yet accepted in air traffic, according to aviation authorities, as it lacks the ability to sense and avoid an obstacle, efficiently enough [5].

II. Literature Review

The last two and a half decades elicits an increased interest, development and research in the fields of Micro Aerial Vehicles (MAVs) [2]. This period saw the growth in more number of ornithopters. Many MAVs and FAVs rose, however some of them proved to be state-of-the-art. Some of these include the Delfly 1 [6], Delfly 2 [6], Delfly Micro [7], Delfly Explorer [8], Harvard RoboBee [9], MicroBat [10], RoboRaven [11], SmartBird [12] by FESTO, etc. which have been briefly described in the subsequent sections.

A book [13] based on the Delfly project was published by the members of the Delft University of Technology, The Netherlands keeping forward the complete analysis and development of Delfly. The Delfly Project was started in 2005 by the Delft University of Technology, as a student assignment, with an objective to build FWMAVs weighing less than 50 grams, capable of a controlled flight. All the versions of Delfly aforementioned carry at least a camera on-board. With the success of Delfly 1, the Delfly 2 project came into existence in 2006. The goal of the Delfly 2 project was to construct a FAV just enough to fit in a 30 cm diameter sphere, which was accomplished in the year 2007, with a wingspan of 28 cm and capabilities to fly forward at 7 m/s and backward at 1 m/s . It was the first IMAV (International Micro Air Vehicle) entity capable of autonomous flight, indoors. The study upon the development of Delfly 2 resulted into the third Delfly version known as the Delfly Micro, which was presented in the year 2008. The Delfly micro is a 3.07g MAV with an onboard video-transmitter and camera as well with a wingspan of 10cm. Further modifications in the design, structure and actuators gave birth to the Delfly Explorer in later half of 2013, which was world's first MAV capable of a fully autonomous flight. All the processing and sensing is done onboard, which helps in its take-off, flight as well as obstacle avoidance.

III. DESIGN AND DEVELOPMENT OF ROBOTIC BIRD

A. *Aerodynamic Principle*

The principles that define the behavior of flight characteristics of a bird or any other aerial organism are defined as the aerodynamic principles. A number of factors are involved in governing the flight of a bird. These factors include the free-stream velocity, angle of attack (AoA), Reynolds's Number, wing membrane flexibility, aspect ratio, boundary-Layer flow, etc.

Majorly, four types of forces affect the flight motion – weight, in downward direction; lift in upward direction or perpendicular to the direction of relative upstream velocity; thrust in the direction of flight; and lastly, drag force in the direction opposite to flight motion. Weight of the component is balanced by lift force, and thrust balances the drag force, during a cruising flight.

Lift force is generated by the use of wings, which may be fixed (ailerons) or flapping. Magnitude of lift generated is significantly dependent upon the upstream velocity, but is also a function of density of the surrounding fluid (air), viscosity, square of the flapping wing velocity, surface area of the wing in contact with boundary layer of flow, as well as the extent of aero-dynamicity of the body. So lower the air density, lighter should be the design of mass system [5]. Additional affecting factors include compressible nature of fluid (air), wing size and AoA. Angle of Attack (AoA) is defined as the angle between the direction of relative free stream velocity, and the chord of the wing. It is thus understood that in order to generate positive lift, lift force produced should be higher than weight force of the model [14]. Upward stroke of the wing gives negative lift which is undesirable and so projected surface area is decreased. Also, the end of upstroke generates additional negative lift due to the change in velocity over wing surface. During the down stroke of the wing, the AoA is negative, while it is positive during the upstroke, which thus results into minimum negative lift. The sign of AoA flips at the extreme flapping positions in the Flapping Plane.

Secondly, is the drag force, which is produced due to body shape, amount of surface area contributing to the boundary layer flow, and the critical angle of attack. Above the critical angle of attack (≈ 15 degrees) results into sudden increase in the drag force on the body which causes it's stalling. Thus, the drag is an inevitable aerodynamic force which can only be reduced; may be by altering the airfoil section, or smoothening of surface layer, thus reducing friction, as well as reducing the chord length so that minimum amount of surface area of wing is in contact with flowing air. The drag force along with lift force perpendicular to upstream velocity induces a resultant lift which reduced the AoA to an effective lesser AoA, as depicted in the Fig.1.

The maximum lift generated limited by its critical AoA can be further increased by introducing the Alula as described in [15] by Meseguer. Alula as shown in Fig. 2 is a high-lift device at the leading or trailing edge of wing, which helps to optimize lift, by increasing the chord of wing or controlling the boundary layer flow. Until the critical AoA is reached, the Alula remains intact with wing, and detaches itself at critical AoA or at 12 m/s i.e. 105 Reynolds's Number (experimentally), thus it possesses a passive functioning. Alula is known to increase Coefficient of lift up to 22%, by extending to only up to 17.5% of wingspan.

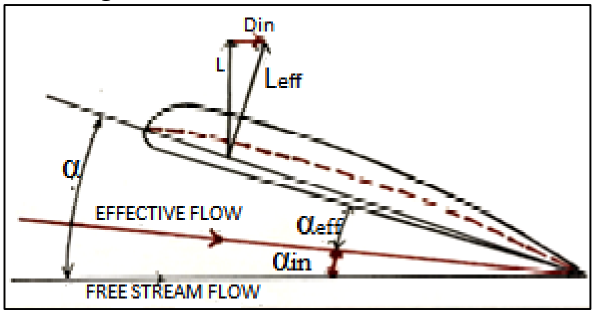


Fig. 1: Effective AoA in airfoil section

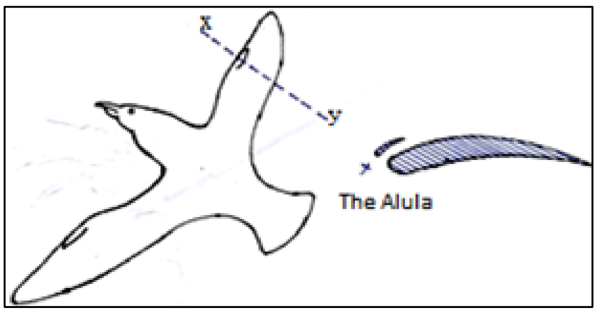


Fig. 2: Alula section

Weight of the device, is another unavoidable entity. However, very light-weight ornithopters have been developed weighing just a few grams RoboBee by Harvard (80 milligrams) [9].

Lastly, thrust is generated due to the usual propellers found in aircrafts, and due to the flapping motion of the wings in case of birds or insects. To sustain a flight, enough thrust needs to be produced so as to balance as well as overcome the drag force acting on the body. Thrust force is produced during the entire flapping cycle; however, primary (positive) lift is generated only during the down stroke.

The primary, significant amount is thrust develops during the down stroke; upstroke also generates thrust but is quantitatively less. However, it is observed that generation of lift and thrust is a directly proportional function of the flapping frequency.

B. Design Criteria

The designing of a MAV demands pre-requisites (thorough knowledge) in the fields of aerodynamics, material science, electronics, electrical, aviation propulsion and artificial intelligence. The concept of biomimicry plays a vital role in designing of an ornithopter. For instance, in [16] the designing of ornithopter is based upon humming-bird. It is observed that the best flying efficiency is for 7.5 degrees of AoA, 5 m/s velocity and 4 Hz of flapping frequency at which majority of the natural flyers flap. Certain design parameters including the aspect ratio and the effects of Reynolds's number on the flight dynamics were studied by Thomas J. Mueller and James D.Delaurier [17], to address some of the problems arising in designing of small scale ornithopters and UAVs.

1) Wing Design

The wing design greatly affects the amount of lift generation. Studies regarding various airfoil sections have been done to determine the optimal design to provide with maximum lift and minimum drag. The Fig.3 shows foil sections of some of the birds. According to Nathan Chronister, an ornithopter hobbyist, the area of the wing should be one-third to that of the wing area.

- The curvature of foil shape resulted from Bernoulli's theorem gives rise to the required lift. Wing loading is defined weight per unit surface area of wing. Higher the wing loading, faster the bird must fly in order to overcome its self-weight.
- For testing purposes, the primitive models can be made from balsa wood and tissue paper. Polyethylene plastic film, water-resistant vinyl tarpaulin, etc can be used to build the wing membrane.
- Generally, the stiffeners used were of carbon fiber (CF) or glass fiber rods. Wherever little flexibility is required CF rods are used, while more flexibility is obtained in case of fiber glass rods. For instance, the 6 micron thick Mylar foil with 2 CFRP stiffeners gave the best results in terms of lift in Delfly 1 [6]. The designing of an MAV along with the reference of the Delfly, Delfly 2 and improved design of Delfly 2, has been described in [18]. The design of the wings is based upon biomimicry derived from a dragonfly (sympetrum vulgatum). Also the detailed structures of the Delfly versions, along with the components are mentioned in [18, 19]. Also, the membrane wing structure as of bats as shown in Fig. 4 is highly preferred due to its higher maneuverability and lift. These membrane wings are the largest observable with stiffeners.
- Wingspan and design is selected on basis of biomimicry, while internal support structure is generally designed keeping that of a bat in mind.
- Most of the lift is generated farther away from the wing root, where maximum deflections of the wings are observed i.e. at wingtips. Also, at higher AoA higher drag forces are observed. However, flexibility of wings leads to lagging in phase, of an average of 3 degrees, of the wingtip as compared to wing root.

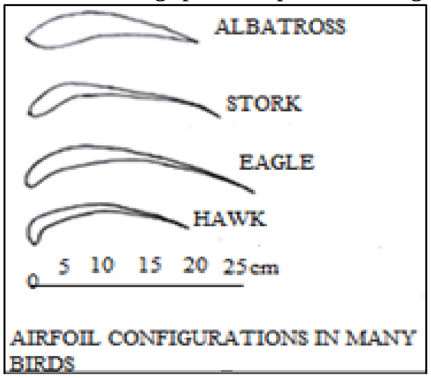


Fig. 3: Wing sectional view

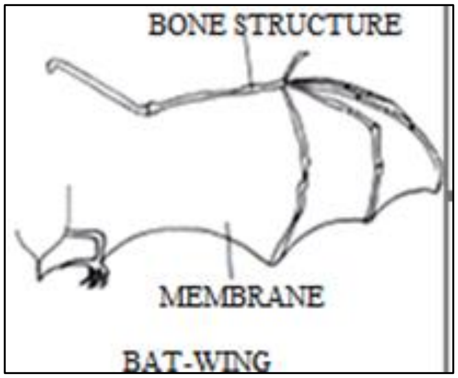


Fig. 4: Bat-wing structure

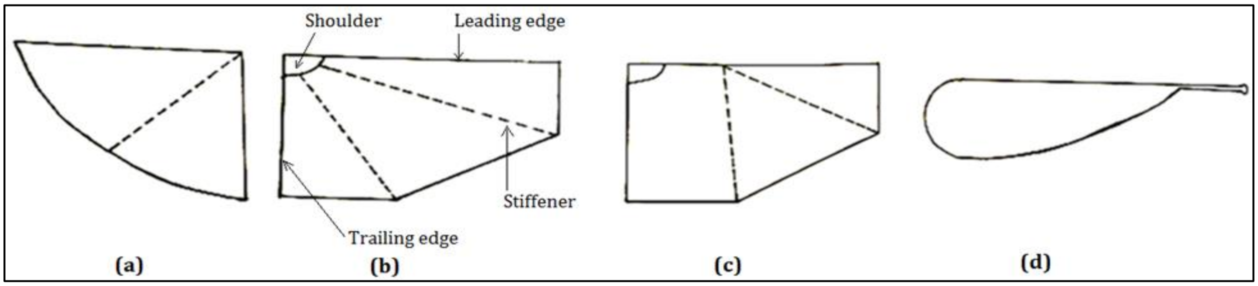


Fig. 5: Wing design (a) consisting of single stiffeners, (b) consisting of double stiffeners hinged at shoulder, (c) consisting of double stiffeners hinged at leading edge, and (d) conventional elliptic wing design

A tiny change in the arrangement of stiffeners in the wings resulted in an increase of 5% in the power efficiency of the wing [20]. The design should be as light as possible, by considering a similar natural counterpart such as a crow, seagull or a large bat. However, the total weight should not exceed the natural value. Through biomimicry, the flapping frequency target should be same as that of natural flyer; not to mention that higher frequency is always desirable. While choosing an appropriate motor, an arbitrary higher value of frequency needs to be assumed. Speed is proportional to one sixth power of mass mathematically represented as,

$$v \propto m^{1/6} \qquad (1)$$

2) Tail and Mainframe Design

The tail of a flying body determines its intensity of maneuverability. The types of motions of an aircraft or a bird include rolling (rotation about axis along length of body), yawing (about vertical axis perpendicular to rolling axis) and pitching (climbing about lateral horizontal axis).

In a conventional aircraft tail design, the pitching motion is imparted due to the elevators, and the combined result of yawing and rolling is due the rudders as shown in Fig. 6 [13]. For smaller deflections of rudder and elevator, linear changes are observed in yawing and pitching motions respectively; however, as the deflection increases, non-linear increment in the overall deflection is observed. Various tail designs developed over the course of time include: conventional aircraft tail with elevator and rudder, tail with a propeller in rudder (to aid yawing-Fig: 7), inverted-V tail, etc. In an inverted-V tail, the lower surfaces produce a combined yawing and rolling motions. Also, this design reduces overall drag and weight forces, but poses landing difficulties which might cause its breakage.

Maneuverability aiding components of some ornithopters have been discussed here. Delfly 1 had a simple inverted-V Shaped tail whose lower surfaces reduced drag by contributing to boundary flow. Although mutual actuations of flaps on either side of tail allowed combined rolling and yawing, landing difficulties with risk of tail damage remained persistent [13]. Unlike Delfly1, Delfly Micro and Delfly 2 (2009) had traditional aircraft tail. It allowed placing tail in wake region of wind flowing through wings, in the later. This arrangement improved stability and control during hovering and cruising flights. Tail-sitters were employed to facilitate vertical take-off and landing easily. However, the effects of interaction of vortices generated by wing with the tail have not yet been studied. Delfly micro tail is made of Polyethylene Terephthalate-Foil. Delfly Explorer used ailerons to allow smooth yawing as in aircrafts, and as a result of which, rudders were removed from tail. Tail (of foam material) had a cross-orientation (Fig: 7 (d)), supporting explorer during take-off and landing.

The super-capacitor powered version of the Microbat had tail stabilizers in it, whose deflections allowed for left or right turns [10]. Plastic foam sheet tail of the battery powered radio-controlled version, had integrated muscle wire actuators. Festo SmartBird had polyurethane foam, inverted-V tail design whose longitudinal axis deflections caused necessary yawing motions. In Harvard RoboBee a discrete tail is replaced by 4-legged support structure for landing and in-flight vertical stability.

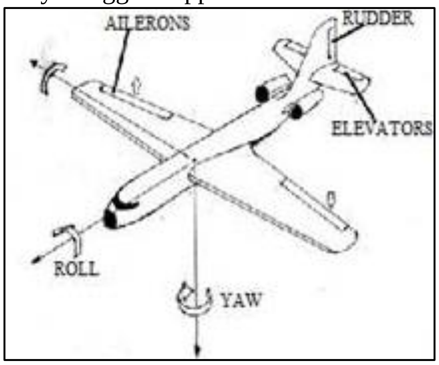
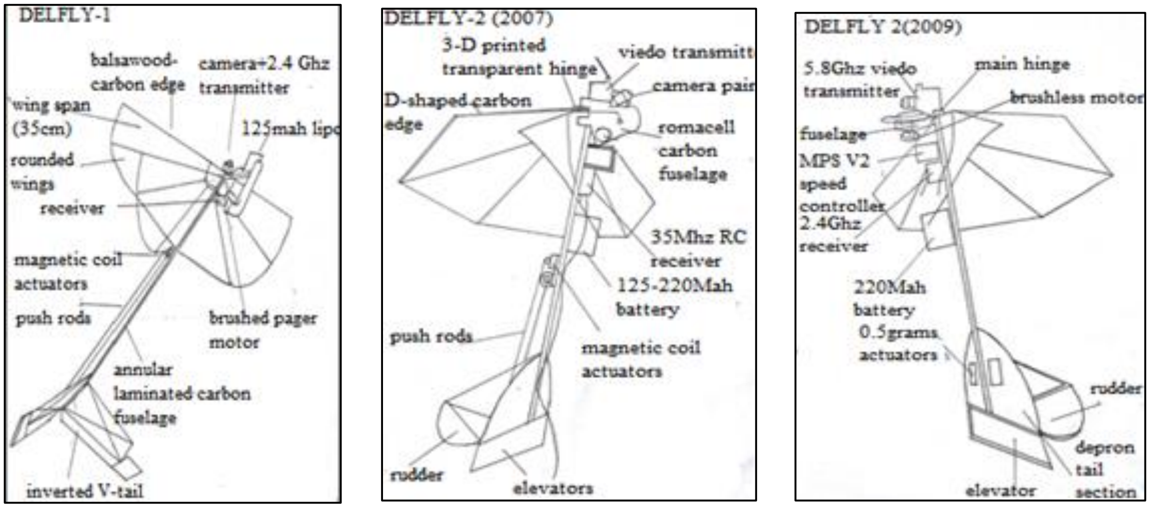
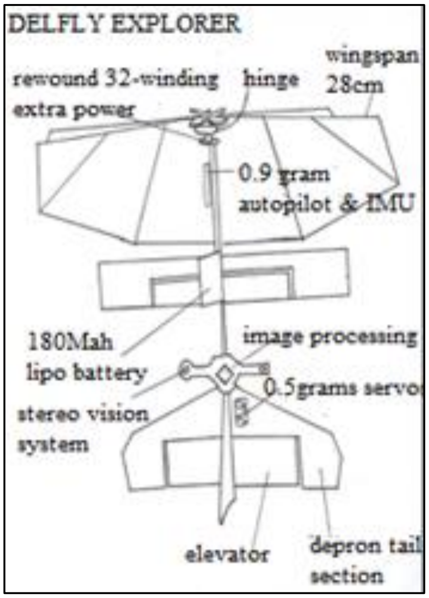


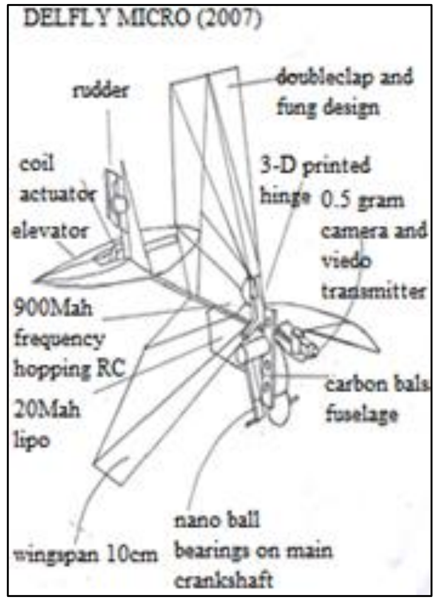
Fig. 6: Conventional elevators, rudders and ailerons



(a) (b) (c)



(d)



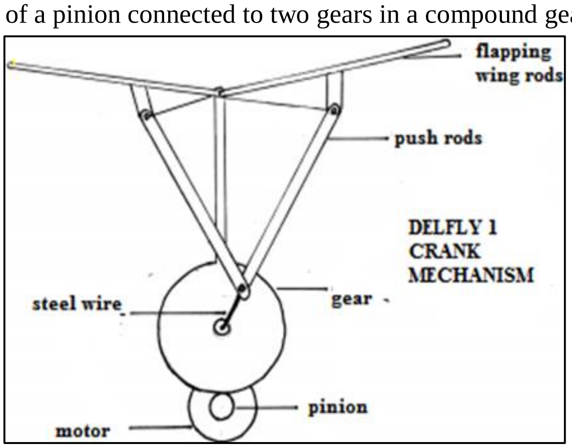
(e)

C. Transmission Mechanism

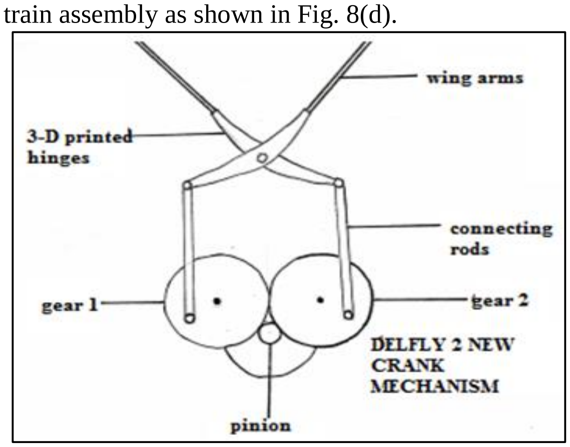
The primary objective of the transmission mechanism is to transform the rotational motion of the motor to the oscillating (flapping) motion of the wings. Generally the motors have low torque and high rpm, so for an adequate amount of lift high torque is required which can overcome the viscous drag caused by the wing flapping. Therefore a high rpm motor with a suitable crank mechanism is to be used for achieving a desired flapping frequency.

The mechanisms for ornithopters can be of various types including a diversity of elements such as servo motors, spur gears, bevel gears, universal joints, bearings, cam-follower, etc. Four as well as five bar mechanisms have been observed in the ornithopters.

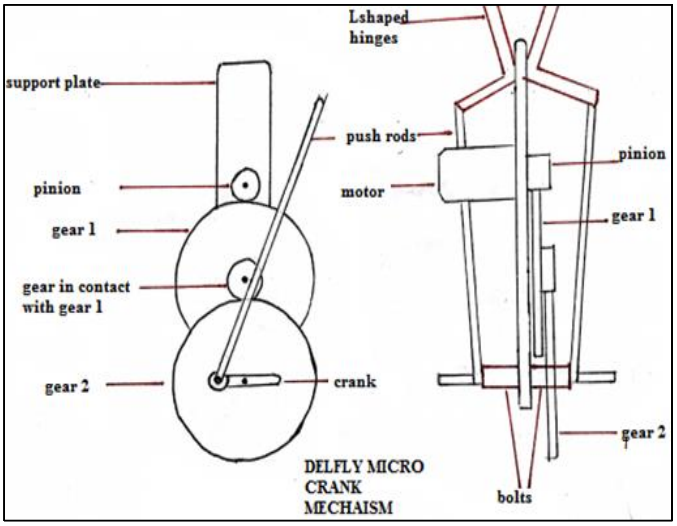
The transmission drive used in Delfly 1 as shown in Fig. 8(a) consisted of a four-bar mechanism comprised of a single pinion and gear. The axis of the actuator and the gear was kept along the direction of flight. Pinion was connected to the shaft of the actuator. Two connecting rods were attached with the center of gear using a z-shaped structure (wire). The rotation of gear imparted flapping motions to both the wings. However, this mechanism led to a phase difference between flapping of both the wings, which resulted into a rotational motion about the axis of direction of flight. Hence, this caused aerodynamic instability to the ornithopter [13]. Now in the Delfly2 the main objective was to eliminate the rocking motion (aerodynamic instability) and the phase difference between the wings of Delfly 1. Therefore, the improved mechanism had its axis aligned along the perpendicular direction of flight. Individual connecting rods were used on both the sides of gear arrangement for separate flapping motion of each wing as shown in Fig. : 8(b). This arrangement resulted into uniform power transmission to the flapping wings thus, smooth fight was achieved. The Delfly micro consists of a compound gear-train of two gears and a pinion as shown in Fig. 8(c), to reduce the speed to a desired value, and obtain the required torque. Two push-rods are attached to the lowermost gear. The size of the components was relatively small so as to manage the assembly in small size of the body. The crank mechanism of the micro-bat is more or less similar to that of the Delfly micro, but in the former, the axis of the gears is aligned along the direction of flight, consisting of a pinion connected to two gears in a compound gear train assembly as shown in Fig. 8(d).



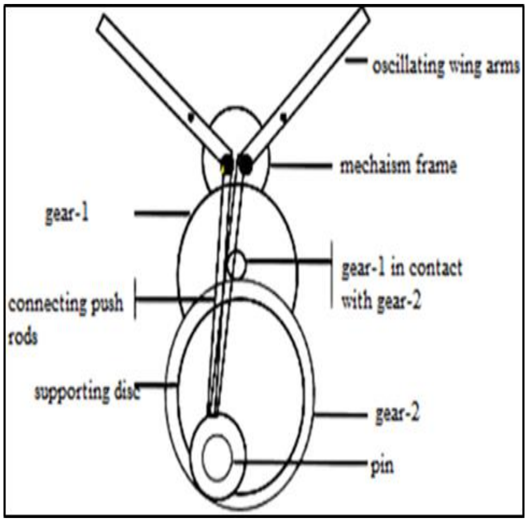
(a)



(b)



(c)



(d)

Two push rods attached near circumference of lower gear, to convert rotational motion of the gear to linearly oscillating motion. The transmission mechanism [21] in case of RoboBee is passive in nature making use of a single piezoelectric actuator. This is because the motor, airfoils, wing foil and stiffeners at such small scale (≈80 milligrams) is not feasible as the surface effects surpass Newtonian forces overcome the lift-generating aerodynamic inertial forces [20]. Hence, the piezoelectric actuator is used at this scale.

D. Materials

Wing is made of materials possessing hybrid characteristics in terms of elasticity, stiffness, strength, higher resistance to wear and tear, and extremely light-weight. Advanced materials used in the development of modern ornithopters such as carbon fiber, Mylar foil, Polyurethane foam, polyester films, Titanium alloys, Parylene C Skin based on the MEMS [22] technology and balsa wood as well. The conventional material selection for wings is generally PET (Polyethylene Terephthalate)-foil and carbon fiber reinforced polymer [23].

In Delfly1, 6 micron Mylar foil along with 2 stiffeners was used to control the increased flexibility, but still due to such high flexibility higher lift was not obtained [6]. This was partly rectified in Delfly2 by using branched stiffeners [13]. Further researching into it more, the Mylar foil was aluminized in the Delfly explorer. The scenario changes when the Smart Bird Festo [12] is to be considered. They used light weight carbon fiber wings and the body/torso is compound of polyurethane foam. This combination is used to compensate the effect of such large dimension against the weight required and the strength necessary [12]. Such an aberration is also seen in Micro-bat where they have manufactured titanium alloy (Ti-6Al-4V) due to the weight and the size limitation. The titanium alloy provides great toughness and ductility [10]. Considering the Harvard RoboBee, they have used polyester material for wing membrane and traditional carbon fiber for stiffeners [9].

E. Actuators

In ornithopters, we require the flapping motion of the wings to generate the lift and thrust. The flapping range is then can be broadly determined between 8 to 50 Hz [23]. These can be done either by linear actuators or through motors. The drawback in case of actuators producing linear motions is the direct relation between the size, mass and the force generated. At a smaller scale, size and mass restrictions are prevalent, and hence these actuators are unable to give sufficient force output to obtain higher frequency. Hence, the conventional DC motors (generally brushless or coreless) and a suitable crank mechanism are used to produce the oscillating motion at desired frequency. The crank mechanism is employed to transform the higher RPM and lower torque of the electric motor to higher torque for overcoming the viscous resistance during flapping.

Actuators used for elevators and rudders were magnetic actuators. Moreover many ways of actuation such as magnetic actuators, conventional servos, muscle wires or Piezo actuators are available. The response time of muscle-wire is more, which results in inefficient control. Piezo actuators are more efficient but they require higher voltages to operate, and the onboard batteries cannot supply it with size and mass restrictions. Thus, generally for tail rudder and elevator control, light-weight and energy efficient magnetic actuators are employed. One such used in Delfly 2 is the Plantraco MiniAct [23].

The selection of the number of actuators to be used in an FAV solely depends on the weight and the size criteria. In Delfly1, 2 only a single brushed coreless motor is used for the whole operation while throwing light on the Festo SmartBird, it is equipped with two servos with actuating force of 3.5 kg for head and tail sections control, and two other servos for wing flapping motion capable to deliver a 45 degree travel in 0.03 seconds [12]. The actuation motor is a compact 135 brushless motor.

For the selection of the right actuator frequency as an affecting factor must be considered. This can be seen in Micro-bat. A small DC motor driven at 1.5 Watts. In no-load condition this power allowed the flapping at 42 Hz frequency without causing overheating of the motor. Adding of the wings reduced the flapping frequency to approximately 30 Hz.

But when the size and the weight criterion is at a critical level as in the case of Harvard RoboBee something unique is used. For the Micro aerial vehicle like RoboBee, which is not more than mere 80milligrams piezoelectric actuators are used. However, the assembly is under-actuated i.e. it is incapable to produce the required rolling and yawing motions [24]. The recent prototypes have depicted a decrease in the overall instability of the MAV through additional actuators, such as air dampers [25]. This actuator is capable of generating a mean lift of 1.3mN at optimal performance in RoboBee. However, the actuation of piezoelectric actuators [26] possesses the major issues in use of high-voltage generally derived from low-voltage power supplies and, recovery of unused energy from the actuators.

F. Power Source

Many sources of power are available to provide energy to the actuators in case of ornithopters, majorly electrochemical because other sources including nuclear energy or internal combustion engine is not applicable at this scale. The concept of integration of solar panels upon the wing surface for increasing the overall endurance flight time has been studied by Wei Zhang and Chao Hu in [27].

A given aircraft can lift a limited payload mass plus energy source mass with a given amount of maneuverability. Moreover when the battery is drained it can deliver some amount of power for a short flight but this might not be very sufficient. So the power-to-weight ratio determines that how much small battery can deliver a sustainable flight [13].

Types of electrochemical power sources include lithium-polymer, lithium-sulphur, Ni-Cd batteries; etc. The most common electrochemical power source is a Lithium-Polymer (LiPo) battery, which has a high power density, energy-to-weight and power-to-weight ratios available in variable shapes and sizes. These batteries provide with greater efficiency as compared to the Ni-Cd batteries. Lithium sulphur batteries possess twice the energy density as to that of LiPo batteries, but do not have the required power-density. The only drawback of lithium-sulphur batteries is that it is not yet available commercially [23]. A lithium polymer battery can discharge up to 10times its capacity(commonly referred as 10C) with specially selected batteries which are capable of delivering 25C so that short bursts of power is delivered when flapping of wings is required.

Factors such as Energy-to-Weight ratios and Power-to-Weight ratios determine the selection of appropriate power source for the Aerial vehicle. Lithium polymers batteries easily available in the market were used for Delfly chain including Delfly1, Delfly 2 and Delfly micro. The Delfly 1 requires ≈0.56 W to power itself. The newest types of these batteries are capable of delivering energy density of 170 Wh/Kg and 4000 W/Kg of power density [13]. A total of 3 Watt is required to power all the components of Delfly 2. To suffice a flight time goal of 6 minutes, theoretically 0.3 Wh battery would be required, so a commercially available single LiPo battery of 0.5 Wh capacity and weighing 4 grams was selected for the same [13]. The discharge was enough to power a 16.07 grams device and providing 14Hz of flapping frequency. The power requirement of Delfly micro was ≈0.6 W for which a 30mAh LiPo battery was used. The discharge of the battery was capable to power 3.07 gram Delfly micro, for 3 minutes with 30Hz flapping frequency, along with a 900 MHz frequency hopping remote-controlled system and a 0.5 gram camera and video transmitter [13]. The MAV can fly for 3 minutes within a range of 50 meters [7]. The advancement in the design of the Delfly led to an increased payload of 0.98 g of autopilot components, and a 4 g stereo system as well. For the explorer with gross weight of 20 g, lift generated by 3.5 V source is enough to sustain its flight for 8-10 minutes with flapping frequency of 12 Hz. The battery used is 180mAh LiPo [13].

In micro-Bat Sanyo Ni-Cd N-50 3.5grams battery was used. A dc-to-dc voltage converter was installed to convert 1 Volt output of battery to 4 to 6 volts; however the voltage output was kept variable. The single cell and converter had advantages in terms of weight, power and energy. Smart Bird Festo is equipped with the conventional lithium polymer batteries. The device was powered by 2 LiPo 7.4V 450mAh batteries and the power requirement is 23W for the motor and control regulation components.

G. Sensors and Controllers

The selection of the computing hardware is one of the deciding factors to be considered for the designing of the FAV. This is because the payload capacity depends on the weight of the processing hardware. For an autonomous FAV there needs to be a micro-processor which gathers all the required information from the onboard sensors and give the required feedback. There are many such micro-processors like ARIES PC/104-Plus, ELEKTRA PC/104 SBC [28] and ADLINK CM1-86DX3 DUAL CORE VORTEX86DX3 [29] etc. Orientation and velocity are typically used to describe the state of an aircraft because the body's position doesn't generally play a part in the vehicle dynamics. This of course discounts environmental effects like wind and obstructions [30]. Therefore the various kinds of inertial sensors are used to keep the FAV stable. Some popular commercial available inertial sensors are 3DM-GX1 [31] and 3DM-GX3 [31]. Of the two sensors, the 3DM-GX1 was better suited for both personal navigation and immersive virtual reality training because of the improved accuracy in highly dynamic motions [32] Sometimes instead of micro-processor and sensors, microcontroller, 3-axis accelerometers, gyros, magnetometers, and a barometer are used.

For an example, to operate Delfly 2 as an autonomous FAV, a ATMega88pa 8-bit microcontroller was used that could even read the dual gyro – IDG500 along with a 2.4GHz DelTang receiver. In order to achieve a pressure signal SCP1000 barometer was installed onto some of the models [13]. Whereas in the Harvard Robo Bee numerous adaptive controllers like adaptive attitude controller, adaptive lateral controller adaptive altitude controller were used for autonomous flight [9]. In Robo Raven the ardiuno nano is used as a micro-controller along with a Spektrum 2.4 GHz Receiver for guiding the controller and actuating the 3 motors. There is a complete RC control in the roboraven [11]. Festo is one of the ideal FAVs to be considered. The onboard electronics allow precise control of the wing torsion as a function of the wing position. For this they have used the 2-way radio transmission with Zig-bee protocol. This can transfer data such as battery charge, power consumption and the various inputs given by the pilot.

It has an independent module (not revealed) for intelligent maneuvering and optimized efficiency [33]. Microbat has indeed a versatile mode of maneuvering in the air. The transmission is a simple RC circuit of a frequency of 916MHz. To reduce the noise created by such a signal digital encoding was done by using a Microchip Technology brand 8-bit microcontroller, commonly called a PIC chip. This component has sufficient processing power, with low power consumption, and small size and weight [10]. The Delfly explorer is an autonomous flapping MAV. It is equipped with ATmega328P - MLF28 microcontroller, 3-axis accelerometers, gyros, magnetometers, and a barometer. With the co-ordination of all these it can autopilot and hence performing height control, disturbance rejection or more precise attitude control is done [8].

IV. CONCLUSION

Through the comparative study of various ornithopters and UAVs, certain observations are made. Increased research, development and interest in the field of UAVs since the last two and half decades has given birth to devices with unmatched similitude with the natural flyers, however, scope of research is still seen in some areas.

Majorly, the already developed FAVs exhibit fixed amplitude and fixed flapping frequency trends. Incorporating the former characteristics allows for variable climb and thrust during flight as per the requirement. We also know that upward stroke results into negative lift, and thus, reducing the effective wing surface area during upward stroke drastically lowers the negative lift. This can be done by twisting the wing during upward motion. Numerous other techniques can be researched with the objective of reducing the anti-lift. A natural bird-flight like maneuverability is still in myth in this field and the example of Festo SmartBird is the closest yet to this goal. Although the Festo claims to have achieved autonomous flight successfully avoiding obstacles, it is not yet capable of independent take-off and landing. In a nutshell, only a marginal number of the models developed today, possess autonomous, robust flight with onboard power source as well as a camera vision feed. It was also observed that none of the ornithopters possessed backward flying ability which can prove to be a significant need during surveillance and rescue operations in narrowed places like tunnels, and holes. Space constraints may not permit turning of ornithopters and thus, backward flying helps.

Thus field of robotic bird being an emerging one, has plenty of future research scope. Hereby are the areas that can be focused upon:

- Fixed amplitude and variable frequency flapping motion of wings.
- Development of wing-twisting mechanism
- Progression in the technique to reduce negative lift generated during the upstroke of wing(s).
- Provision of increased versatile maneuvering capabilities.
- Innovating techniques for independent successful take-off and landing techniques.
- Only a marginal number of the models developed today, possess autonomous, robust flight with onboard power source as well as a camera vision feed.
- Inventing techniques that allow backward-flying trends.

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ABBREVIATIONS

F.A.V- Flapping aerial vehicle
U.A.V- Unmanned aerial vehicle

M.A.V- Micro aerial vehicle
F.M.A.V- Flapping micro aerial vehicle
A.O.A- Angle of attack
MEMS- Microelectromechanical system
LiPo- lithium polymer
PIC- Peripheral interface controller