Development of Flapping Wing Aerial Vehicle

Prof. Ashish M. Dharme[1],Prof. Shalaka H. Joshi[2]

[1]*Assistant professor, Department of Mechanical Engineering, PES's Modern college of Engineering, Pune,ashishdharme@gmail.com*
[2]*Assistant professor, Department of Mechanical Engineering, Zeal college of Engineering, Pune, shalakahjoshi@gmail.com*

ABSTRACT

In this paper, an ornithopter prototype that mimics the flapping motion of bird flight is developed, and the lift and thrust generation characteristics of wing design are evaluated. Simple and accurate flight dynamics models are needed to develop control algorithms to autonomously perform the challenging missions envisioned for these vehicles. In comparison with fixed-wing or rotary-wing machines, ornithopters offer potential advantages that include increased Maneuverability, lower power consumption, higher adaptability to varying situations, and the ability to hover. Our current ornithopter is radio-controlled and capable of hover and landing.this paper also describe the design and development of gearbox for ornithopter and review the sensing techniques

***Keywords**: ornithopter ,maneuverability, hover, mimics, envisioned.*

I. INTRODUCTION

ORNITHOPTERS, miniature flapping-wing air vehicles mimicking avian flight gaits, are receiving growing interest from hobbyists, researchers, and mission planners as these vehicles continue to proliferate in both civilian and military sectors. It is visualized that the agility, maneuverability, robustness, and contextual camouflage exhibited by these vehicles will fill a niche in the design space left void by conventional fixed-wing and rotary-wing vehicles, and result in a fully autonomous flight vehicle that integrates multisession capabilities such as long endurance outdoor flight, super-agile indoor flight, and precision perching.

The human desire to duplicate bird flight has existed for hundreds of years. From Leonardo Da Vinci's drawings to Otto Lilienthal's gliders, the first five hundred years of flapping flight research focused on human transport. Today flapping flight research has shifted to a much smaller scale with the goal of an autonomous ornithopter. Unmanned air vehicle (UAV). Flapping wing vehicles can fill the niche left by traditional fixed and rotary wing vehicles for small, maneuverable and stealthy UAVs in military, civilian and research applications. ornithopter autonomy has not yet been achieved because the kinematics, aerodynamics and the stability, guidance and navigation of birds are much more complicated than that of a fixed wing aircraft.

This challenging problem has sparked a wave of research in dynamic modeling, flapping aerodynamics, structural behavior, and control methods. While it is unlikely that humans can engineer ornithopters that perform as well as nature's flyers in the near term, improvements can be made by characterizing the behavior and optimizing the design of ornithopter wings for optimum aerodynamic performance and flight control. The goal of this project is to provide a predictive aerodynamic model for future autonomous ornithopter control applications.

Fig[1]. Ornithopter test vehicle

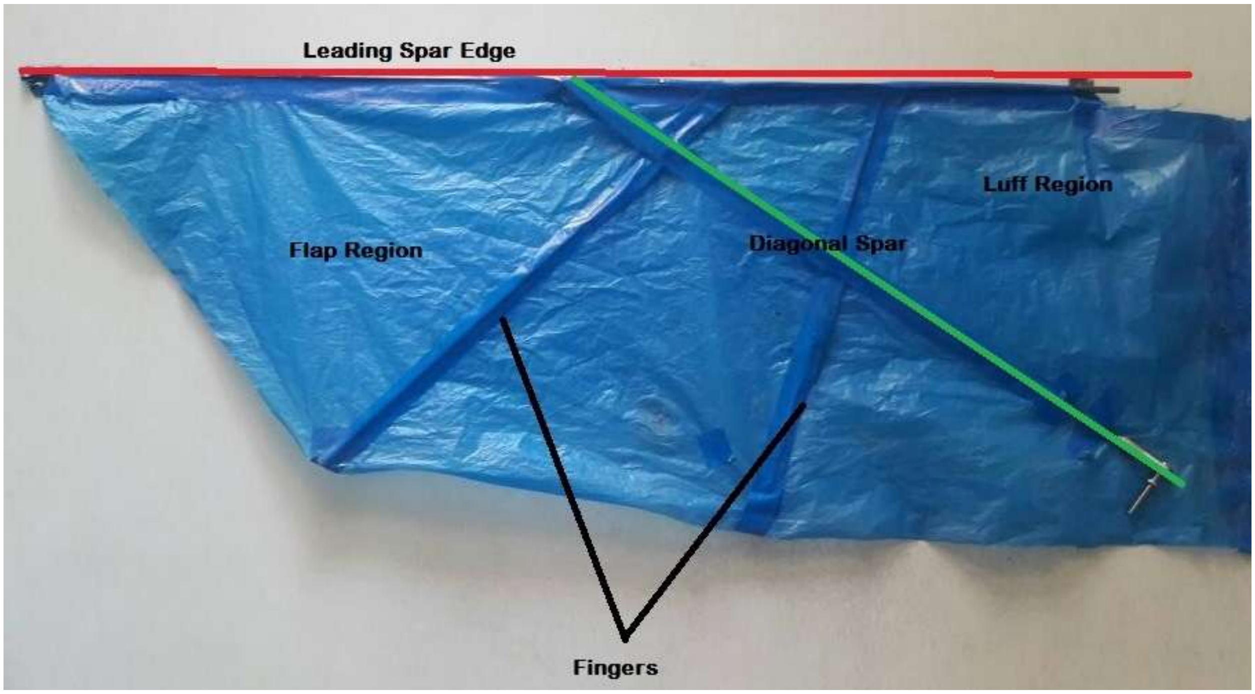
2. UAV MISSION DEFINITON & MOTIVATION

UAV uses have broadened significantly since their invention, but all missions require carrying a payload for experimentation, deployment, or reconnaissance purposes. Two typical military UAV applications were established over a hundred years ago: to seek out a target and deploy weapons, or to seek a target and provide surveillance; add communications to these two tasks and the general spectrum of military UAV missions is completed. NASA recently compiled a more specific set of tasks for civilian UAVs which are listed below.

- Boarder and Coastal Patrol and Monitoring
- Law Enforcement and Disaster Operations
- Digital Mapping and Planning/Land Management
- Search and Rescue
- Fire Detection and Firefighting Management
- Communications and Broadcast Services
- Ground Transportation Monitoring and Control
- Satellite Augmentation Systems
- Air Traffic Control Support
- Power Transmission Line Monitoring
- Environmental Research and Air Quality Management/Control

3. ORNITHOPTER WING DSIGN AND DYNAMIC BEHAVIOR

For steady level flight conditions the ornithopters flap their wings three to sixtimes per second and can reach speeds of thirty kilometers per hour. Wingconstruction consists of nylon stretched over a network of carbon fiber spars andfingers. The ornithopter wings are shown in Figure[2]. There are two spars, one at the leading edge and another placed diagonally from the leading edge to the rear of the fuselage. Each spar is held in place by a Dacron tape pocket to add stiffness and durability. This spar arrangement creates two regions in the wing, the triangular “luff” region, which is a loose membrane, andthe “flap” region which is kept taught by a series of fingers that run from the diagonalspar to the trailing edge.This skeletal and membrane wing structure is more reminiscent of a bat than a bird and the wing behavior exhibits this fact. The flexible skeleton-membranestructure allows for highly dynamic passive shape change as the wing moves throughthe air, as demonstrated by the high speed photo sequence of Figure[3] . Thisflapping sequence shows the down stroke on the left and the upstroke on the right in acounterclockwise circle.



Fig[2]. Wing structure with leading edge and diagonal spars and trailing edge fingers.

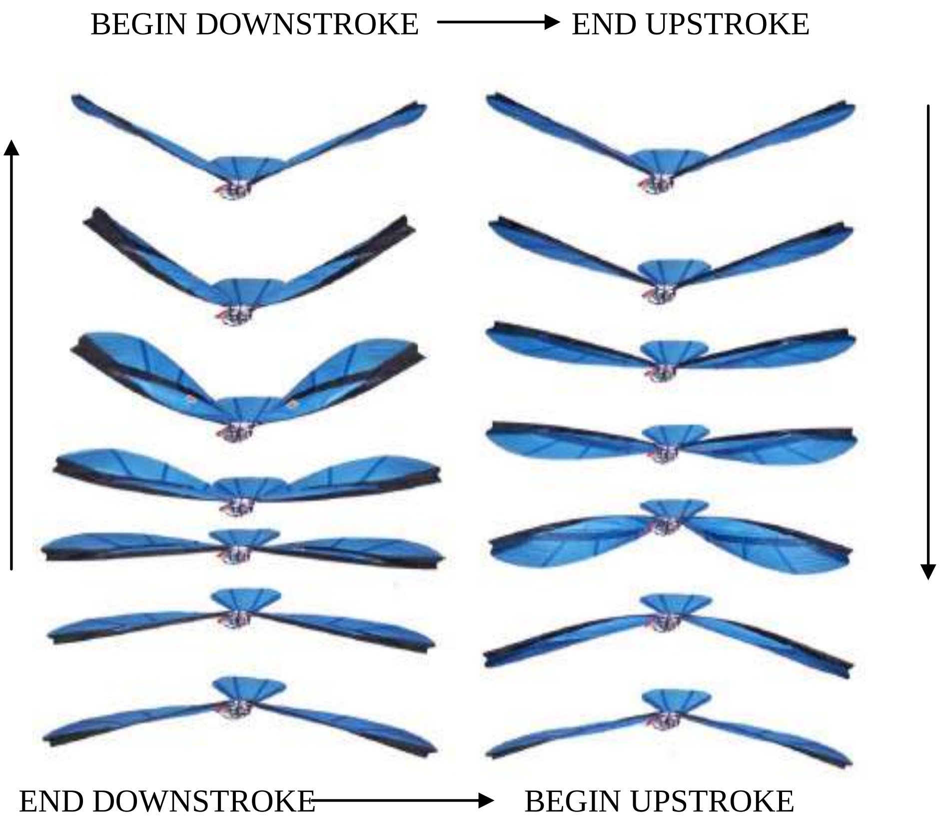
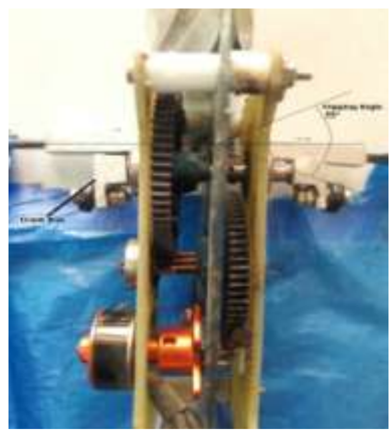


Fig [3].High speed photography of the stroke cycle of the ornithopter. Down stroke ispresented on the left column, starting at the top of the figure and ending at the bottom. Upstrokebegins at the bottom of the right column and continues to the top of the right column.

4. ORNITHOPTER FLIGHT SYSTEMS

The flight systems on the ornithopters consist of a drive mechanism andpower assembly, remote control receiver, servo operated directional control of thetail, and Aunique gear train, shown in Figure[4], drives the flapping motionof the wing with the gears varying in size, depending on the desired flapping rate.Unlike most drive mechanisms the gears are integrated parallel to the fuselage ratherthan perpendicular which reduces the body profile. The crank arm designated inFigure provides a slightly asymmetric flapping angle at the wing root which averages five degrees higher at the maximum stroke angle(30°) than the minimum stroke angle (-25°)

The gear train is powered by a 2 or 3 cell lithium polymer battery withoperation between 7.4 and 11.1 volts and durations of ten to twenty minutes depending on battery age, steady or climbing flight requirements, and wind speed. The battery powers a speed controller which takes input from the receiver for voltage regulation to control the electric motor speed and therefore the flapping frequency.These components are identified in Figure[4].



Fig[4].Front view of ornithopter shows drive gear and crank arms that flap the wing.

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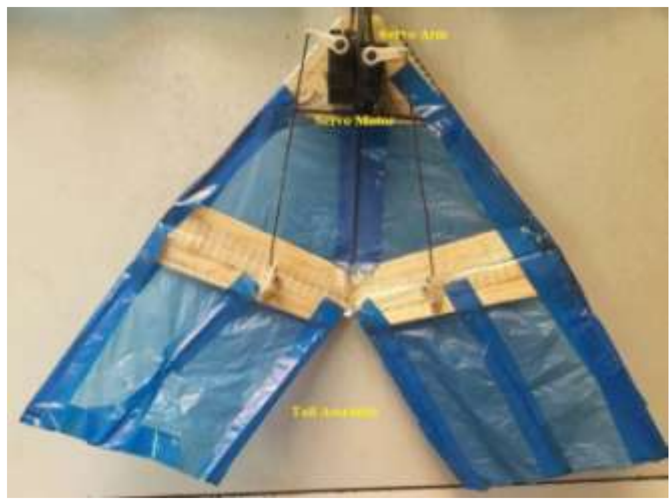
Fig[5].Right hand side of ornithopter. Components from left to right include RC receiver, speed controller, electric motor, drive gear and crank arm.

5. TAIL

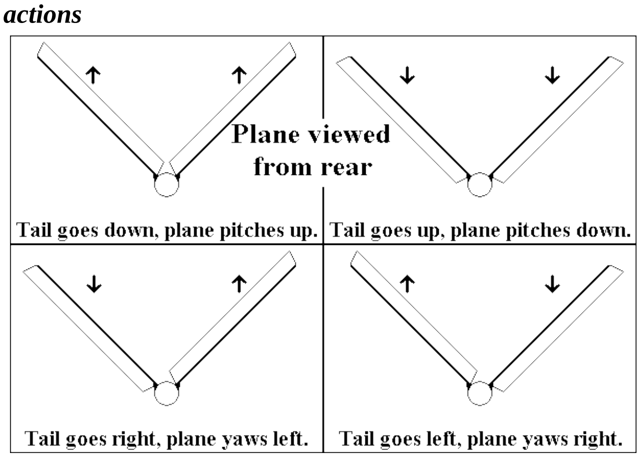
The tail section of the ornithopter is responsible for both of the controllable degreesof freedom aside from the ability to throttle the drive motor. The tail of theornithopteris set up with two servo directly mounted on the tail connected via a linkage.the elevator and rudder are naturallycoupled with two servos, with V-tail configuration. The V-tail mixing allows the control the direction of ornithopter. The two servos controls the by using alinkage not only does the pitching motion to up and down movement and yaw motion for left and right. Smaller servo to be used to get mechanical advantages. In addition to this, the servo, a major point ofweight on the ornithopter, is moved forward in the frame. While not obviously anissue it becomes important once the center of gravity must be placed because theframe ends up rear-heavy.



Fig[6].The tail section of the ornithopter. The tail uses a V tail configuration todecouple the elevator and rudder actions

6. WINGS

The wing design chosen for use for the ornithopter is a proven design by Sean Kinkadeand is used throughout his line of ornithopter designs which shows that it scales well. The wings have a triangular support structure made from carbon rods.A main spar runs along the leading edge of the wing and a strut connects from therear of the ornithopter's body to a point near the tip of the main spar. From thisstrut there are several smaller carbon rods that project to the edge of the wing whichare somewhat free to move. This results in a fanning motion from the trailing edge ofthe wing that produces thrust while the leading edge is flapping up and down whichdirectly contributes a part of the lift in addition to the conventional lift coming fromairflow over the wing. Working from the specifications of the Kestrel ornithopter and the new payloadcapacity necessary an approximate size for the scaled up wing was found



Fig[7]. V tail configuration todecouple the elevator and rudder actions based onthe wing loading. With its 0.22 square meter wing area and overall weight of 395grams the Kestrel has a wing loading of 1.78 kg/m2 . Scaling to a larger machine thateven the size of is known is a pretty dificult proposition, but a few assumptions canbe applied to clean up the situation. The payload fraction, or amount of payloaddivided by the overall weight of the ornithoper is assumed to be constant. For theKestrel this number is 0.334 with a payload of 132 grams. The 132 gram payload wasestimated by looking at the difference between the weights of onboard components likethe batteries as equipped and the maximum weighs allowed (using lithium polymerbatteries vs nickel metal hydride for example). The estimated required payload for thePhoenix is 400 grams which, using the same payload fraction, comes to a total weightof 1197 grams. With this weight in order keep the same wing loading as the Kestrelthe Phoenix will need a wing area of 0.672 square meters. By scaling the originalKestrel wing the desired wingspan comes to about 2 meters. The actual wingspanused in the design was shortened to 1.8 meters in order to make the ornithopter easierto handle through the lab with the option left open to increase the wingspan withlonger spars if necessary.

Fig[8].The Wing assembly of the ornithopter.

7. EXPERIMENTAL METHODS

Experimental design, testing, and analysis provide the most importantinformation to the flapping flight field of research because experiments measureactual aerodynamic performance and describe the motion of the wing and the fluiddynamic response to the motion. The aerodynamic design and testing of anornithopter focuses on the wing and the mechanism driving the flapping process.DeLaurier produced two large scale ornithopters, one model with a span ofapproximately nine feet and another large enough for a human passenger . Hiswork focused on the wing design, including analysis of structural flexibility,aerodynamic performance and stability and control with documented wind tunnel andflight tests. Raney et al. provides an overview of biologically inspired micro airvehicles and the experimental design of a hummingbird style wing and flappingmechanism that is tuned to the resonance of the structure like an insect . Flappingmechanisms and wing platform design are examined by Malolan et al. who measured lift using strain gauge instrumentation to find the optimal membrane wing design forvarious free stream velocities . Additional wind tunnel research by this groupexplored the lift, thrust and unsteady aerodynamic effects on the wing by changingparameters such as aspect ratio, reduced frequency, advance ratio and planform shape. The effect of Strouhal number on the performance of a flapping membrane wingdesign optimized by Malolan is explored by Aditya, with important results relating tooptimal thrust . Another detailed flexible wing design and aeroelastic analysis isgiven by Unger et al with performance comparisons to a rigid airfoil . DeLuca et
al. used wind tunnel tests and XFOIL predictive code to show that flexible membranewings further delayed stall and increased lift-to drag ratios by 30 percent over rigidfixed wings .

Experimental analysis of membrane aerodynamics at low Reynolds numbers is presented by Tamai et al. with research inspiration from bat flight . Particle Image Velocimetry was utilized by Rojratsirikul et al. to study the unsteadyaerodynamics of a two dimensional membrane airfoil. This study also includesmeasurements of the membrane shape, dynamic analysis of membrane vibrationmodes, and flow visualization as the angle of attack and velocity change tounderstand the effects of separation on membrane oscillationsThere are many more technical papers involving experimental designs andaerodynamic analysis than those provided above.

8. CONCLUSION

In this paper the case for the construction of a large scale ornithopter suitable forcontrol systems research is motivated. In order to work with the dynamics and controls of a flapping wing flying vehicle while these future targets are currently in development scaled up version has been designed and constructed. With its larger payload capacity it's capable of carrying a fully equipped computer and high-end inertial measurement unit with the option of future additions of GPS or other more exotic sensors.The ornithopter was designed from the ground up with the needs of research inmind. All components have been designed to be as lightweight and high performanceas possible so as to maximize payload capacity and are intended to fail in predicableand field repairable ways. Examples of this are the screw in wing spars and replaceableface plates. In addition to this all parts of the ornithopter are simple and inexpensiveto fabricate and assemble.

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