EXPERIMENTAL STUDY ON THE WING STRUCTURE AND SKIN FLEXIBILITY FOR FLAPPING WING OF MICRO AERIAL VEHICLE (MAV)

by

ROHAYATI BINTI AB RASHID

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LIST OF SYMBOLS

α	Angle of attack (deg)
V_∞	Free Stream Velocity (m/s)
J	Advance Ratio
C_L	Lift Coefficients
C_D	Drag Coefficients
b	Wing Span (mm)
f	Frequency (Hz)
Φ	Total wing flapping angle (deg)
L/D	Lift per Drag ratio
L/D_{max}	Maximum Lift per Drag ratio
Θ_w	Wing beat amplitude (deg)
F_w	Wing beat frequency (Hz)
m	Variation with mass (g)
S_{ref}	Reference Wing area (mm^2)
CH1	Channel 1 (Lift)
CH2	Channel 2 (Drag)
$\boldsymbol{l}$	Connecting rod
c	Rocker
s	Position of piston pin from crank center
ϕ_1	Crank angle
ϕ_2	Connecting rod angle
ϕ_3	Rocker angle
p	Piston

r	Crank radius
o	Crank centre
n	Crank pin

LIST OF ABBREVIATIONS

AOA	Angle of Attack
CAD	Computer Aided Design
CFD	Computational Fluid Dynamic
CNC	Computer Numerical Code
DC	Direct Current
Hz	Hertz
MAV	Micro Aerial Vehicle
MALV	Micro Aerial Land Vehicle
PCD	Passive Cavitations Detection
PVC	Polyvinyl Chloride (transparency)
SD	Standard Deviation

KAJIAN EKSPERIMEN KE ATAS STRUKTUR DAN KEBOLEHLENTURAN SAYAP UNTUK PESAWAT UDARA MIKRO BERKEPAK

ABSTRAK

Pesawat udara mikro (MAV) merupakan satu bidang yang agak baru di Malaysia. Kajian terhadap pesawat udara mikro yang dilakukan di makmal Aerodinamik Universiti Sains Malaysia (USM) telah menggalakkan banyak penyelidik dan saintis untuk mempelajari tentang kepentingan dan keupayaan pesawat tanpa juruterbang mikro ini. Pesawat mikro bersayap kepak ini mempunyai potensi yang tinggi untuk aplikasi awam mahupun ketenteraan disebabkan kebolehan pengendalian pada halaju rendah dan mempunyai kecekapan tenaga yang baik berbanding pesawat mikro jenis yang lain. Di dalam kajian ini, eksperimen ke atas mekanisma sayap berkepak di lakukan di dalam kebuk angin. Kajian ini dilakukan dengan menggunakan tiga jenis sayap yang berbeza dari segi struktur iaitu tiga baten, lima baten dan kelawar. Keputusan mendapati struktur jenis kelawar adalah yang terbaik dari segi aerodinamik berbanding dengan yang lain dengan nilai L/Dmax = 1.31 pada $\alpha = 30^o$. Dari segi bahan pula, keputusan mendapati kulit sayap yang daripada jenis getah fleksibel adalah yang terbaik berbanding dengan sayap PVC dengan nilai C_L= 3.9 pada J=0.88 iaitu dalam keadaan aliran tidak tetap. Sayap PVC pula ia adalah yang terbaik apabila dalam keadaan aliran tetap dan sayap jenis getah nipis fleksibel adalah yang terbaik apabila berada di keadaan aliran tidak tetap pada penerbangan kelajuan yang tinggi.

EXPERIMENTAL STUDY ON THE WING STRUCTURE AND SKIN FLEXIBILITY FOR FLAPPING WING OF MICRO AERIAL VEHICLE (MAV)

ABSTRACT

Micro Aerial Vehicle (MAV) in Malaysia is still at an early stage. Therefore, the development of flapping a wing MAV by Aerodynamic Laboratory in School of Mechanical Universiti Sains Malaysia, encourage the local researchers and scientist to study the importance and the capability of flapping a wing MAV. The flapping wing MAV shows great promise in civilian and military applications as it possesses good maneuverability at low speeds and relatively good energy efficiency. Hence, it is vital for the MAV to be able to carry a certain load of additional equipment in accordance to performing its function successfully. In this study, the experimental work is carried on a flapping wing mechanism model and tested in an air chamber. The investigations have been carried out using three different wing structures; a batwing, three battens and five batten wings. The results show that, batwing is the best in aerodynamic performance compared to the other two types of wing with L/D_{max} 1.31 at $\alpha = 30^o$. For the skin flexibility study, the flexible latex thick wing was found to have better overall performance over the rigid wing for flapping flight with C_L= 3.9 at J=0.88, (unsteady state). The PVC rigid wing was found to have better lift production performance for flapping flight in steady condition and the latex thin wing, which is the most flexible among the three tested wings, was found to have the better lift generation performance compared with the latex thick wing for flapping flight, especially for high speed flapping flight applications.

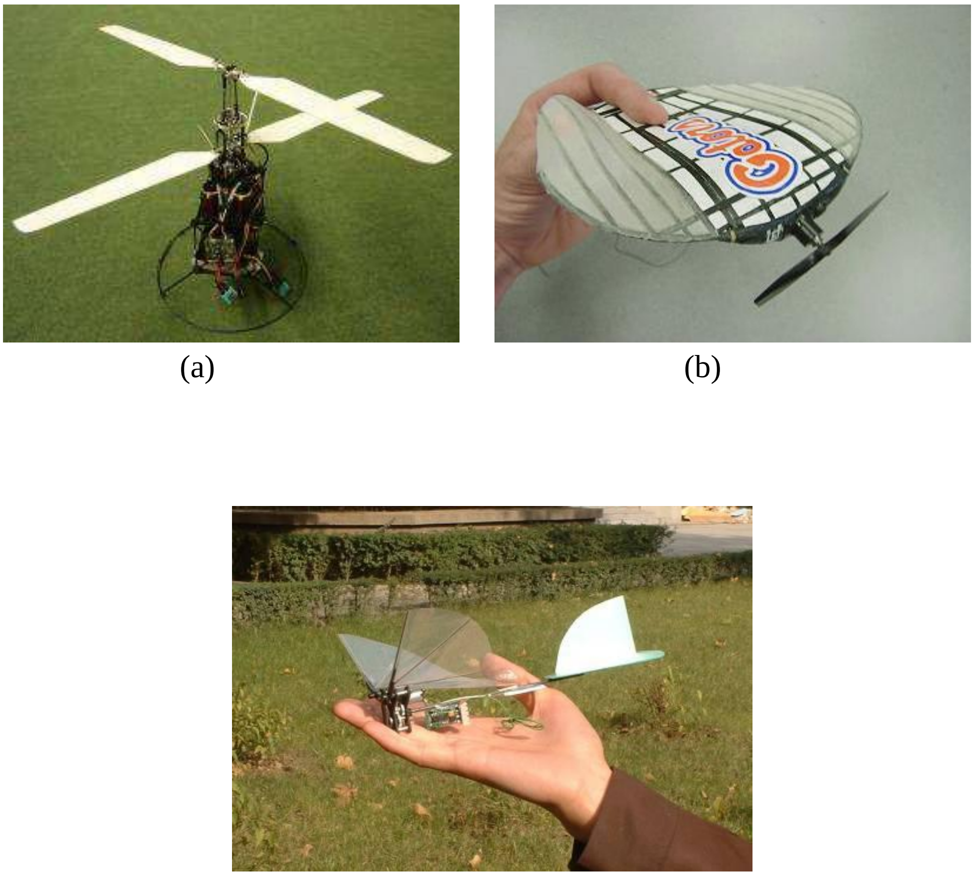
CHAPTER ONE

INTRODUCTION

1.1 Introduction

Within the past decades, Micro Aerial Vehicle (MAV) technology has experienced tremendous development. With rapid progress in material technology, electronics integration and power plant miniaturization, MAV is now being developed and built around the world by various research groups. Such keen interest in pursuing MAV technology is due to its potential for specialized field or indoor deployment.

Generally, MAVs are size restricted with the wingspan of about 100-150 mm and a total mass of about less than 100 grams and fly at the slow speed of a few meters per second. However, due to its small size, the MAV has a small inertia which in turn translates to improved maneuverability and better control over the vehicle. Using wing type categorization, MAVs can be divided into three different groups, which are rotary wing, fix wing and flapping a wing. Another group is hybrid MAVs that, combines the traits of two different wing types. Figure 1.1 shows the example of the rotary, fix and flapping wings.



(a) (b)

(c)

Figure 1.1: (a) Rotary wing (Duranti et. al., 2007), (b) Fixed Wing (Ifju et.al, 2006), (c) Flapping Wing (Olsen et. al., 2005)

As the most common form of mechanical flight, fix wing crafts offer exceptional performance at high speed line cruising. However, although scaled down versions of conventional aircraft design as MAVs are being designed for outdoor applications, the fix wing type MAV scores poorly indoor or in the enclosed environment. Reasons that contribute to its short coming include low agility, which is essential for avoiding an obstacle, and also lacks ability to hover. On the other hand, rotor wing flights possess good agility and vertical takeoff and landing but suffer from wall proximity problems, energy efficiency at small scale and also high noise output when flying.

Ongoing scientific studies conducted on birds and insects flight are being done in hope of being able to emulate and integrate their superior flight mechanics and pattern into man-made electromechanical machines. The desired MAV performance requirements derived from those attributes seen in small birds and insects are high maneuverability, very low speed flight capability, high power and also aerodynamic efficiency.

Such vehicles would be very useful for remote sensing missions where access is usually restricted due to various hazards or space constraints. The goal is to consider a flapping wing design and adaptive flow control as a novel approach to the problem, since the size and speed range of the vehicle closely matches that of small birds and insects, which are obviously a very capable flier. The most striking feature of bird and insect flight is of course the cyclic flapping motion of the wings who generates sufficient lift and thrust to support the body in forward or hovering flight. Large amplitude motion and periodic acceleration and deceleration of the wings lead to large inertial forces, significant unsteady effects, and gross departures from standard linear aerodynamic and aeroelastic theory. However, insects, birds and bats were found to produce complex motions that can consist of flexing, twisting, bending, rotating, or feathering their wings throughout the entire flapping cycle.

1.2 Application of MAV

Essentially MAVs are built to assist in service military or civilian missions. Equipped with a video camera or a sensor, these vehicles can perform tasks like surveillance and reconnaissance, targeting, and bio-chemical sensing at hazardous location. Hence its capability at lifting a small payload is vital when carrying out the tasks.

With a camera, a small MAV can also be used to monitor the condition and state of any type of high structures such as monuments, buildings or water towers for periodic maintenance checks. The vehicle will provide a visual survey of the target subject, and people can easily detect faults without physically being there. If any problem exists, subsequent technical personnel can be dispatched to rectify the issue. The MAV could also be adapted to many other civilian applications, including guiding fire and rescue operations, monitoring traffic, forestry and wildlife surveys and in real estate aerial photography.

The MAV's true potential can be displayed in the battlefield for up to date feedback information to the current situation. MAVs are fully autonomous and small enough to be carried by a single infantryman. Thus, the infantryman can be deployed for applications such as rescuing or reconnaissance for life information by the second information were obtained via the vision of the MAV.

1.3 Problem Statement

The MAV that used flapping a wing has potentially higher efficiency than an aircraft with a rotating propeller. Flapping wings do not stall as easily as fixed wings, because the cyclical motion does not allow much time for a stall to develop. The incredible maneuvering of birds is partly due to their small size and partly due to their use of flapping wings. Flapping wings might not seem like the best choice for a manned aircraft, because all that wing flapping tends to result in a bumpy ride. However, there are some ways to solve that problem. Besides, the effect of flapping a wing is better than normal fixed wing in terms of improved efficiency, more lift high maneuverability and reduced noise. It is important to understand the fundamentals and capability of flapping a wing in the form of generating better lift compare to fixed wing. Furthermore, wing structure design and wing skin flexibility are essential elements in the flapping wing study because these parts give more effect to the aerodynamic performance for the flapping wing MAV.

1.4 Objective

The objectives of this study are:

- To compare among the three different types of wing structure for the flapping wing Micro Aerial Vehicle (MAV).
- To study the effect of flexibility wing skin material for the flapping wing.
- To perform experimental testing of lift generation at free stream velocity, flapping frequencies and angles of attack on the flapping wing Micro Aerial Vehicle (MAV).

1.5 Scope of Study

The emphasis of the research is on the aerodynamic performance of three different types of wing structure geometry and three different types of materials of wing skin flexibility study. These wings with different structure are 3 battens, 5 battens and batwing. The outcome from this experiment is lifting and drag coefficient, which depends on parameters such as the angle of attack (-10 deg to 50 deg), air velocity (V= 2.0 m/s to 8.0 m/s), and flapping wing frequency (6.0 Hz to 10.0 Hz). In order to obtain required parameter, an experiment was carried out using air chamber as air flow supply. Strain gauge balance is used for lift and drag measurements and Kyowa PCD 300A sensor interface data as a data acquisition system.

1.6 Thesis Outline

Chapter One gives a brief review on the history and background of the research conducted. Research problem is identified in this section, which also defines all the objectives to be attained during the research.

Chapter Two explores all literatures on related works carried out by other researchers. The focus here was on mechanism design of flapping a wing; wing structure study and material, which were used in the skin flexibility study.

Chapter Three describes the experimental procedure and explains more on the materials that were used in this present study.

In Chapter Four, the experimental results are discussed. Finally, Chapter Five is presenting the conclusion of the study and recommendation for future works.

CHAPTER TWO
LITERATURE SURVEY

2.1 Introduction

This chapter discusses the work that has been carried out by previous researchers on lift, drag and thrust generated by a flapping wing Micro Aerial Vehicle (MAV) or insect like flight and how other parameters such as the angle of attack, wind speed and flapping frequency affect flight. Since each research paper utilizes a different model of the flapping wing MAV, each paper's experimental values are different, but they reached to the common generic conclusion as a result. The research done for further understanding of forces involved in the flapping wing flight and also the specific kinematics of wing motion. This research involves three different approaches; design three different wing configurations, different wing skin flexibility and testing in stationary flow using air chamber.

2.2 Flapping Wing Mechanism

Since this study is using a flapping wing mechanism, it is useful to study available mechanism and typical designs that are commonly used. It is found that certain mechanisms are capable of flapping at higher frequencies than others. The type of pitch motions varies between the mechanisms with some can dynamically change pitch, while others have fixed pitch envelopes. The information is gathered from mechanism designed by several research such as Isaac (2006), McIntosh (2006), Sirirak (2001), Lin (2006), Bachmann (2008), Tsai (2009), Maglasang (2006) ,Zbikowski (2005) and others.

There are various flapping wing mechanisms that have been developed to measure aerodynamic forces. For example, the mechanism developed by Isaac et al. (2006) produced both dynamically changing pitching and flapping motions. The main flapping was driven by a motor which drove a flywheel with a connecting rod. The connecting rod was connected to the wing with the use of a fixed pivot joint. Pitching motions were done through the use of a servomotor. This motor is attached below the fixed pivot point so the entire motor assembly was flapped as well, with the servomotor directly driving the pitch change of the wing. This is one of the very few mechanisms, which can produce controllable changing pitching and plunging motions on the fly. The flapping frequencies used are low, and the mechanism is flapping in water. Producing a mechanism which can produce higher flapping frequencies and dynamically controllable pitching motions on the fly is a significant challenge.

Mcintosh et al. (2006) have been successful in creating a mechanism which is capable of flapping two rigid wings while being able to change the pitching angle. This mechanism has a distinct feature: both the pitching and flapping mechanisms were created through the use of a single actuator. The motion created by this mechanism is similar to many insects, wherein the wing is rotated at the top and bottom of each flap. Flapping frequencies of 1.2 to 1.9 Hz are generated. The drive mechanism is again a connecting rod and gear assembly to produce the main plunging motions. Pitching motion is generated through the use of various bending and torsion springs and a pin and follower assembled. The mechanism varies its pitch during the flap. It is not controllable on the fly, meaning the mechanism must be stopped and reconfigured to produce a different set of pitching potions. An image of this mechanism can be seen in Figure 2.1.

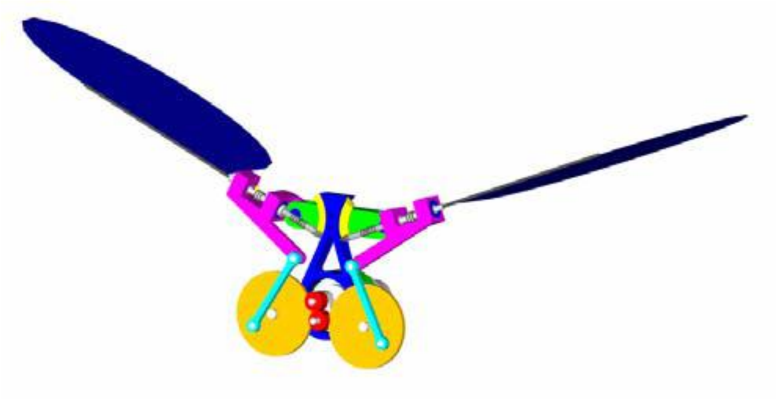


Figure 2.1: Mechanism Capable of Biaxial Rotation [Mcintosh et al. (2006)]

Sirirak et al. (2001) have developed a micro aerial vehicle (MAV) with MEMS based membrane wings. These wings were made of titanium-alloy (Ti6Al-4V) for the wing's frame, and parylene C for the skin. The study mainly focused on insect wings. A drive mechanism converting rotary motion to the flapping motion of the wings was designed. Figure 2.2 shows the picture of the drive mechanism used as well as the completed mechanism.

Figure 2.2: Microbat Transmission System and Fabricated UAV

[Sirirak et al. (2001)]

This design consists of a small DC motor with a 22:1 gearing reduction ratio turning a geared flywheel which in turn drives a scotch yoke crankshaft in the vertical motion. The crankshaft is restricted in motion so it can only move in the vertical direction. This mechanism is capable of flapping at 42 Hz when no wings are attached, and at 30 Hz with wings.

Lin et al. (2006) reported the lift and thrust generated by the ornithopter's flapping membrane wings with simple flapping motion in their article. They revealed that the lift force of a flexible flapping wing will increases with the increased of the flapping frequency under corresponding flying speed. For the same flapping frequency, the flying speed can be increased by decreasing the angle of attack with the effect of losing some lifting force. The flapping motion generates the thrust to acquire the flying speed. The combination of flying speed and angle of attack generate the lift force for flying. Figure 2.3 shows the assembly of the mechanism, motor and the battery set.

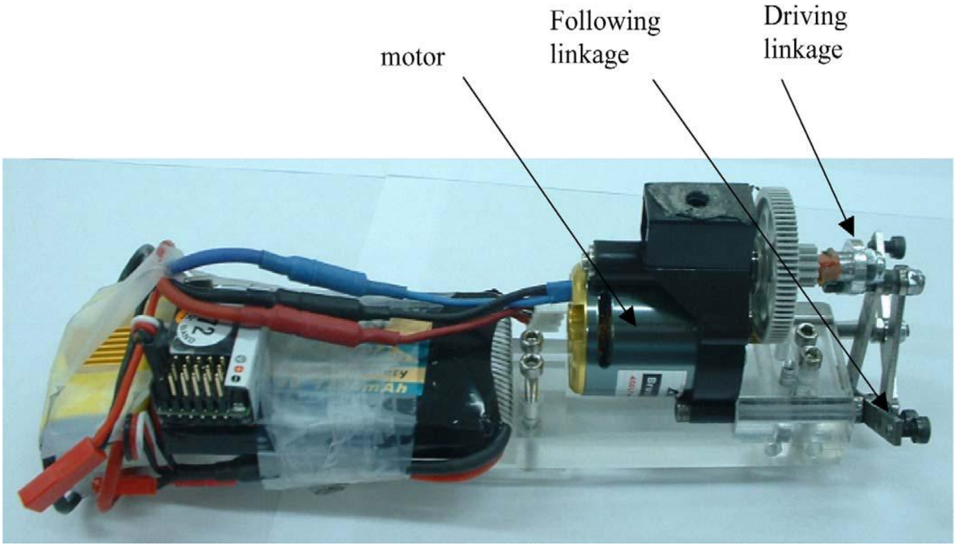


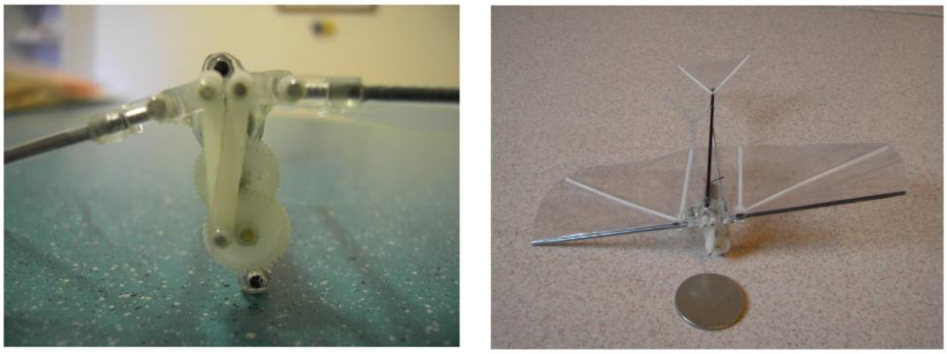
Figure 2.3 : Assembly of the mechanism, motor and the battery set [Lin et al. (2006)]

Bachmann et al. (2008) reported on the design, fabrication, and field testing of a small (30.5 cm wingspan) robot capable of aerial and terrestrial locomotion. The micro air-land vehicle (MALV) shown in Figure 2.4 flies using a chord-wise, under cambered, bat-like the compliant wings and walks over rough terrain using passively compliant wheel-leg running gear. MALV successfully performed transitions from flight to walking and in some situations, from walking to flight. Its lightweight (100 g) carbon fiber vehicle can fly, land, and crawl with a sensor payload exceeding 20% its own mass.

Figure 2.4 : Micro air-land vehicle (MALV) [Bachmann et al. (2008)]

Tsai et al. (2009) have studied the design and aerodynamic performance of a planar membrane wing as shape airfoil for the micro aerial vehicle illustrated in Figure 2.5. They employed the concept of four bar linkage to design a flapping mechanism which simulates the flapping motion of a bird. The angles of upstroke and down stroke are varied in the design. The total flapping angle is 73^o. The flapping frequency of wing is 25.58 Hz. The power source comes from motor with a Li–H battery. A simple flight test was carried out and the result of the flight is good.

The actual flight distance was approximately 8 m, and the primary goal was achieved. They also found the rigidity of tail wing was crucial and should be enhanced to prevent the flapping wing MAV for improve their performance.



(a) (b)

Figure 2.5: (a) Transmission mechanism (b) The MAV entity

[Tsai et al. (2009)]

Maglasang et al. (2006) have studied the aerodynamic mechanization concept for the flapping wing aerial vehicles. They investigated the feasibility of a highly efficient flapping system that is capable of avian maneuvers such as the rapid takeoff, hover and gliding. Numerical and experimental studies have been conducted on the flapping wing kinematics and aerodynamics, and on the mechanization and design requirements for a bird-like micro aerial vehicle (MAV). An unsteady viscous flow simulation was performed using a 3D Navier-Stokes code in investigating the effects of dynamic stall phenomenon on the propulsive efficiency, thrust, and lift of the flapping wing. A mechanical flapping-wing micro aerial vehicle that utilizes both the flapping and feathering characteristics of a typical pigeon (*Columba livia*) had been successfully constructed, and it achieved excellent aerodynamic performance during preliminary wind tunnel testing. The flapping-feathering mechanism employed in this MAV model shown in Figure 2.6 were synthesized and constructed to best describe the properly coordinated flapping and feathering motions of the wing at an optimum phase angle difference of 90° in a horizontal steady level flight condition.

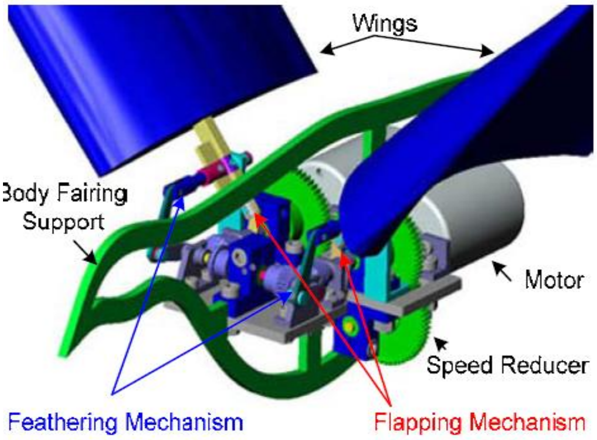


Figure 2.6: The flapping-wing MAV model [Maglasang et al (2006)]

Zbikowski et al. (2005) described the concept of a four-bar linkage mechanism for the flapping wing of micro air vehicles and outlines its design, implementation, and testing. They not only construct a test bed for aeromechanical research on hovering in this mode of flight, but also to provide a precursor design for a future flapping-wing MAV. The mechanical realizations are to be based on a four-bar linkage combined with a spatial articulation. The former was found theoretically attractive, but impractical, while the latter was both theoretically and practically feasible. This led to a combination of Watt’s straight-line mechanism with a drive train utilizing a Geneva wheel and a spatial articulation as shown in Figure 2.7.

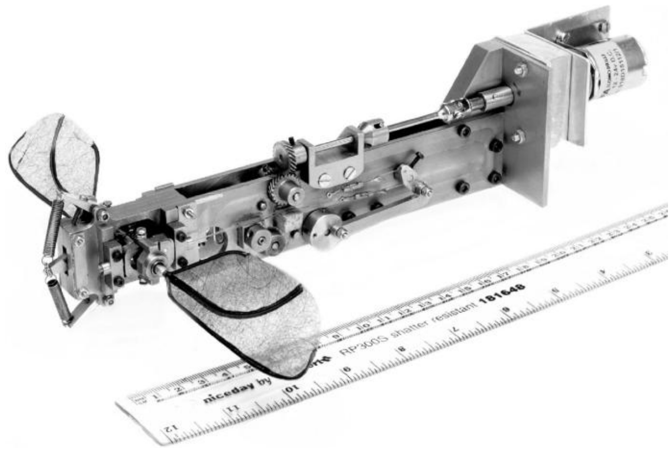


Figure 2.7 : Four-Bar Linkage Mechanism for Insect like Flapping Wings in Hover [Zbikowski et al (2005)]

Madangopal et al. (2006) had presented an energetic based design of a mechanical flapping-wing machine that significantly reduced the peak torque requirement of a drive motor. This was motivated from the study of insect flight in which the thorax of the insect acts as an energy storage unit, which stores the kinetic energy of the wings as elastic potential energy and releases this energy during the subsequent stroke. In this manner, the work done by the muscles, which need to drive the wings from the rest at the start of every stroke, is considerably reduced. Analogous to the insect thorax, the design made used of tension springs that are so attached that they increased the torque during the upstroke and reduce the same during the down stroke, thereby reducing the sharp variation in the torque over the entire cycle and keeping its value within the peak torque requirements of the drive motor.

2.3 Wing Geometry of Natural Flappers

The present study also involved designing a flexible wing to be used in the flapping experiment. Therefore, it is helpful to observe the various types of wings natural flyers that have been developed.

Raney and Slominski (2003) have studied the mechanization and control concepts for biologically inspired micro aerial vehicles. Structural approaches, mechanical design, sensing and wing beat control concepts inspired by hummingbirds, bats and insects were examined. Experimental results from a test bed capable of generating vibratory wing beat patterns that approximately match those exhibited by hummingbirds in hover, cruise, and reverse flight were presented. A structural concept from an existing MAV design was adapted to create wings having size, weight and platform based on an appropriately scaled hummingbird example. The structure consisted of a carbon-epoxy composite frame covered by a thin layer of latex similar to the battened membrane structure of a bat wing. The wing exhibited a vibratory resonance at the flapping frequency of an equivalently sized hummingbird. A mechanization concept was developed for a biologically inspired vibratory flapping test bed that provided control over wingtip trajectories generated by the system. A means of varying the test bed actuation signals to generate wing beat patterns that approximately matched those exhibited by hummingbirds in hover, cruise, and reverse flight were implemented.

Khan et al. (2005) had presented a method for investigating the unsteady aerodynamics of flapping wings for micro air vehicle application. For this purpose, a robotic flapper was designed and fabricated. It can flap dynamically scaled wings in a desired kinematic pattern. An aerodynamic model and wing testing methodology were developed based on unsteady aerodynamic mechanisms. This model additionally accounted for the wing twisting. The experimental results show a good agreement with published data, and the aerodynamic model were similar with the experimental results.

2.4 Wing Skin flexibility Study

Since the flapping wing MAVs fly typically at low Reynolds numbers, gusting and disturbances in the flow are more problematic. It has been shown that the flapping wing based MAVs have certain advantages compared to their fixed wing ability to hover, react more efficiently to gusts, have a lower weight and generate lift without excessive size and weight (Ifju et al.,2006).

Ifju et al. (2006) had designed a series of flexible and fixed wing MAVs (Figure 2.8) as an effort to determine the role of wing flexibility in flight. They had developed the flexible wing for MAVs that incorporates a carbon fiber skeleton and thin extensible membrane. The skin significant billowing, bending and washout was documented for a series of wings with different flexibility. The results were of high fidelity and can be used to validate future numerical models.

Figure 2.8 : Flexible Wing UAV Developed at the University of Florida [Ifju et al (2006)]

Ho et al. (2003) revealed that the size of unsteady leading edge vortex was observed to depend on the advance ratio. No vortex was created and the flow was always attached at large advance ratios ($J > 1$; quasi-steady flow). However, as the advance ratio decreased below unity, the unsteady leading edge vortex appeared at any wing chord size. Greater vorticity on the upper surface translates to lower pressure and leads to a greater lift force. The confirmation of this theory was obtained by experiments to compare two wings where the inboard region of one wing was removed. As shown in Figure 2.9, lift coefficients for both wings are the same, proving that the removal of the inboard region has no effect on lift. However, experiments showed a significant drop in the coefficient of thrust at low advance ratios for the wing without the inboard region. Thrust produced was highly influenced by wing flexibility and orientation, which govern the vortices shed at the wing's trailing edge.

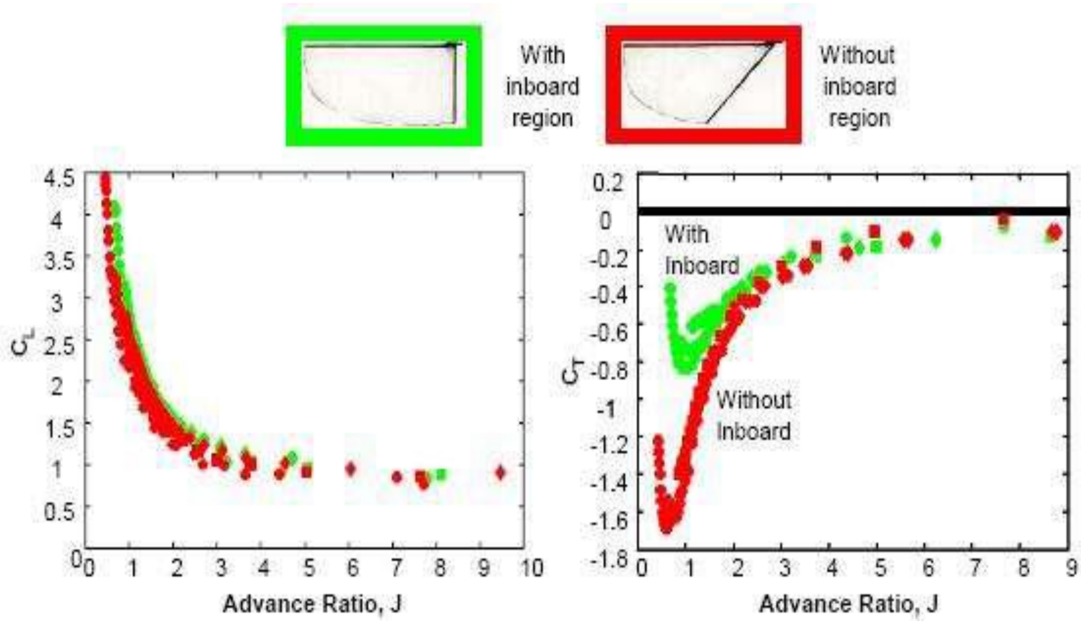


Figure 2.9 : Lift and thrust production as a function of wing area. (Ho et. al., 2003)

Different wing size does not significantly affect the lift forces produced during flapping flight at variable wind speeds and angles of attack, as proven in works done by Lin et al. (2006). Experiments were performed with two different wingspans of 60cm and 40cm. Both wings were constructed with similar materials; epoxy reinforced carbon fiber of wing spars and wing membrane made from PVC film as shown in Figure 2.10. Its means that the larger wing deformations along the wing span will disturb the air flow, thus causing air flow distortions, which reduce the lift produced.

(a) (b)

Figure 2.10 : Different wing sizes. (a) 60cm (b) 40cm (C.S.Lin et. al., 2006)

Shyy et al. (1999) had examined the flapping and flexible wings for biological and micro air vehicle. Based on observation of biological flight vehicles, it appears that wing motion, and flexible airfoils are two keys attributes for flight at low Reynold's number. The small size of MAVs corresponded in nature to small birds, which do not glide like large birds, but instead flap with considerable change of wing shape during a single flapping cycle. With flapping and flexible wings, birds overcame the deteriorating aerodynamic performance under steady flow conditions by employing unsteady mechanisms. In general the down stroke is the most valuable part of the flapping cycle, where the wings are fully extended, producing both lift and thrust at the same time. During the upstroke, the wings are partly flexed to reduce the moment inertia and drag of the wings.

Singh et al. (2004) had conducted experiments on the insect based flapping wings for micro hovering air vehicles. They compared nine different wings with different wing skin, and they found that the thrust and power generated by bio mimetic, flapping pitching wings has been measured at high frequencies. The mass of the wing was found to have a large impact on the maximum frequency attainable with the mechanism. Because of this, a number of light composite wings were manufactured and tested at high frequencies. However, all these wings showed a drop in thrust at high frequencies while some of the lighter wings were so flexible that they did not produce any significant thrust.

Lian et al. (2003) had studied the aerodynamics of membrane and corresponding rigid wings under the MAV flight condition. The membrane wing was observed to yield desirable characteristics in delaying stall as well as adapting to the unsteady flight environment, which intrinsic to the designated flight speed. Flow structures associated with the low Reynolds number and low aspect ratio wing, such as the pressure distribution, separation bubble and tip vortex were also reviewed. Structural dynamics in response to the surrounding flow field were presented to highlight the multiple time-scale phenomena. Based on the computational capabilities for treating moving boundary problems, wing shape optimizations can be conducted in automatic manners. To enhance the lift, the effect of endplates was evaluated. The proper orthogonal decomposition method was also discussed as an economic tool to describe the flow structure around a wing and to facilitate flow and vehicle control.

2.5 Literature Summary

In the previous study, numerous experimental studies have been conducted in recent years to investigate the flow pattern and vortex structures in the wakes of flapping wings. More works have been done to study the variations of the resultant aerodynamic forces (lift and thrust) acting on the flapping wings with phase angle of up to stroke and down stroke within a flapping cycle. However, very limited literature can be found to quantify the overall aerodynamic performance of flapping wings (i.e., how much time average lift and thrust can be generated by flapping wings) as functions of flapping frequency, forward flight speed, as well as the angle of attack of the flapping plane with respect to incoming flows. For the development of engineered flapping-wing MAVs, such as information is extremely important because the performances of the MAVs, such as the vehicle size, payload, and flight speed, would be totally determined by the mean lift and thrust that can be produced by the flapping wings. Therefore, this research will further study of the best method and material for the flapping wing because it is necessary in order to provide better aerodynamic performance in the future design.

CHAPTER THREE

MATERIALS AND METHODS

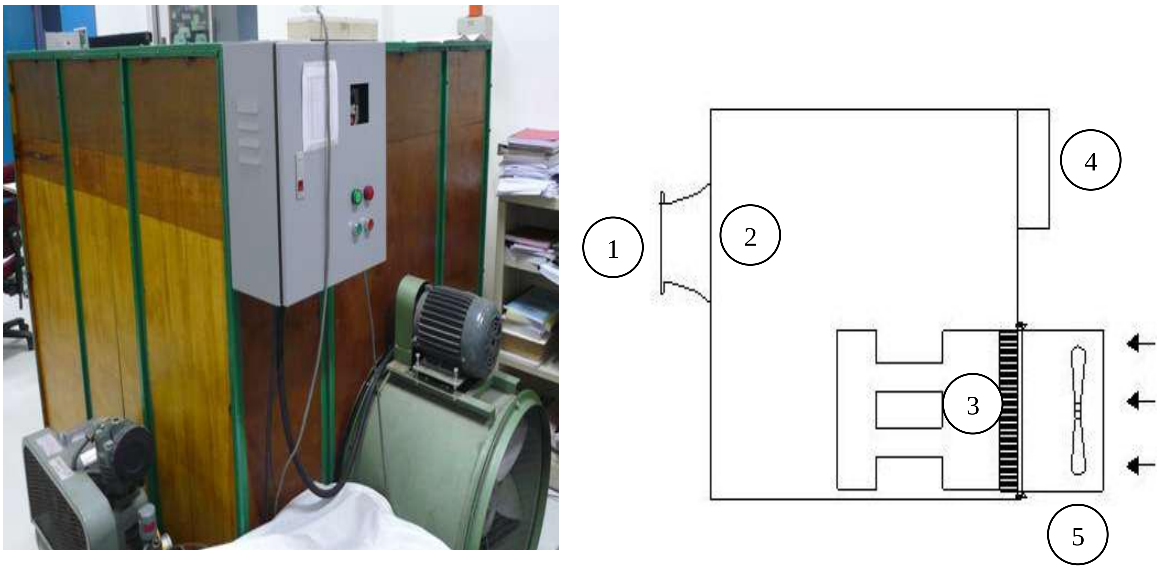
3.1 Introduction

Experimental study of the flapping wing MAV was done with the aid of a strain gauge balance unit and an air chamber. The experimental setup and system components are specified and explained in this chapter and also included is the design of three tested wings with different structure and wing skin flexibility study. Then, the techniques used for force measurements and connection between the strain gauge balance, and the data acquisition system are discussed.

3.2 Experimental Apparatus

3.2.1 Air Chamber

The air flow chamber supplies the wind velocities necessary for conducting the experiment at variable wind speeds as shown in Figure 3.1.An air chamber of 1.5m x 1.5m x 1.5m is used to supply air flow to the test section (1). Air chamber was developed by Fazli (2005) to provide a laminar uniform flow regime. A convergence nozzle of 30cm^2 x 30 cm^2 (2) made by aluminum is used to supply air flow to the flapping mechanism. A honeycomb (3) located in front of a fan is used as flow straightening. A plastic air blockage is used in front of honeycomb to improve air velocity profile. A three-phase axial fan (5) controlled by a digital transformer is used to control air velocity. Air chamber can provide the maximum air velocity of 15 m/s and air velocity magnitude is measured by using a digital flow meter. The fan located at the rear of the chamber is used to generate the required wing velocities. The air intake is first stored in a reservoir before it was channeled out to reduce possible turbulence. Air flow speed can be digitally controlled via the control unit (4) as the air velocity increases with turbine rotational frequency.



(a) (b)

Figure 3.1: Air chamber. (a) Front view (b) Schematic drawing view

3.2.2 Flapping Wing Mechanism

The model flapping wing mechanism MAV used for this testing aerodynamic analysis in this study is the four bar linkage mechanism which was designed by Yusof et al. (2009). Essentially, the flapping mechanism has the maximum power, and torque were estimated by assuming; (1) maximum load for two wings is 6 gram and acts through the wing's aerodynamic centre; (2) maximum wing beat frequency is 10 Hz; (3) maximum wing span is 12 cm. The maximum torque required to move the wing from the bottom position to the top in the flapping motion is 45 mN.m. The DC micromotor and planetary gear head have been chosen to drive the flapper. The nominal operating voltage is 15 volts, the maximum torque, of the motor is 1.86 mN.m, with a maximum speed 12000 rpm and a current rating at 0.18 A. Using a 4:1 reduction ratio of planetary gear heads, this increases the maximum torque of the motor up to 300 mN.m and the speed of the motor reduced to 5000 rpm. The DC micromotor, the planetary gear head and Magnetic encoder were fixed together as illustrated in Figure 3.2 (a).

Notice that the maximum torque available to move the wing between 33 up to 45 mN.m, is seven times the torque produced by the motor that was enough torque to successfully flap the wing. The other 80% of the torque is needed to overcome the inertia resistance of the flapper and air friction during wing flap. At such high frequencies the flapping motion becomes distorted sinusoidal and reliable motions were achieved for frequencies up to 12 Hz, due to the operating limitation of the driving motor and the transmission system.