ANALYSIS STUDY OF LIFT FORCE GENERATION USING SEMI-RIGID FLAPPING WING

A.F.Hawary[1], C.H.Lee[1], E.A. Bakar [1],N.R. Mat Noor[2] and W.A.F.W. Othman[2]

[1]School of Aerospace Engineering,
Engineering Campus, Universiti Sains Malaysia,
Nibong Tebal, Malaysia.

[2]School of Electrical and Electronic Engineering,
Engineering Campus, Universiti Sains Malaysia,
Nibong Tebal, Malaysia.

Corresponding Author's Email: [1]aefaizul@usm.my

ABSTRACT: A wing flapping mechanism with span variation analogous to eagle wing was developed in this project. The flapping motion which imposes the required kinematics was designed according to the bird flapping mechanism with the corresponding motor driven/gearbox mechanism and visualized using CAD software. The rotary motion of the motor is converted to linear motion by driving linkage to provide a continuous bird-like wing flapping motion. The 1 Degree Of Freedom (DOF) flapping wing structure, which flap about the spar joint was further developed and fabricated into prototype with appropriate materials. Based on the model, the lift characteristics of flapping flight were investigated at various angles of attack, wind tunnel speeds and flapping frequencies with the aids of wing tunnel. The model was tested at the range of 0 o to 15 o of angle of attack (AOA), wind speed at 8.5 m/s and frequency of 3.185Hz. Lift characteristic of the flapping wing responding proportional to angle of attack and wind speed and flapping frequency are presented.

KEYWORDS: *Unmanned aerial vehicle, flapping wing, UAV*

1.0 INTRODUCTION

Nothing in the creation exhibits fixed wing flight behavior or propeller-driven thrust due to its aerodynamic characteristic(Han, Nguyen, & Han, 2019). Everything ranged from insect to bird that maintains sustained flight use flapping wings. The wings help the birds pierce through air by thrusting them to make numerous incredible maneuvering actions. Flapping wing is an increasingly important feature especially for Micro Aerial Vehicle (MAV) and Ornithopter where all of its lift and thrust were derived from a set of flapping wings (Tuncer & Platzer, 1996). It has several advantages over conventional fixed-wing in terms of propulsive efficiency, its quietness, its ability to carry out short takeoff and landing, and the capability for impressive maneuver in restrictive environments and hovering(Mueller, 2001). The challenge lies in the lack of analytical tools, the shortage of experimental wind tunnel, flight test data and also, the limitation to get the accurate modeling of the biological wing due to its complex design and flexible nature. Another challenge is the ability to simulate the motion of a biological flapping wing, which undergoes constant changes to optimize the flight (Tuncer & Kaya, 2005). This study focuses on developing a working prototype of a semi-solid flapping wings, so that the characteristic of the wing can be analyzed.

2.0 SETUP & METHODOLOGY

The operational setup of the measurement method is presented schematically in the Figure 1. The development of this system provides the accuracy and repeatability control of devices typically used for flapping wing force measurements. With the use of an air chamber, where the wind velocities can be tailored, the testing of lift of this particular flapping wing model was performed. The wing mechanism was mounted to a jig where strain gauge was installed. The secured connection translates the flapping wing force (thrust) into the strain gauge as electrical signals. The strain gauge is connected to the Kyowa data acquisition system. The analog signals obtained from the strain gauge were fed into the data acquisition system to be conditioned into useful data for detail analysis.

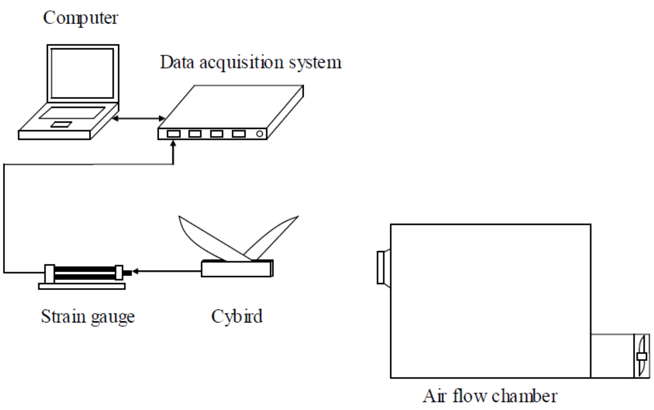
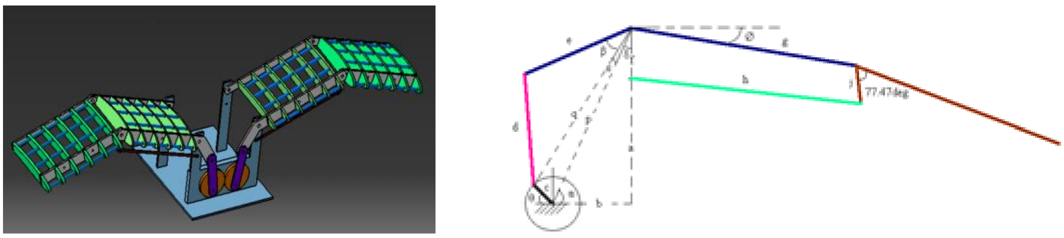


Figure 1: Experimental setup

Figure 1: shows the design of the 3-Dimensional flapping wing model using CATIA V5R16.

The flapping motion is governed by the rotation of the gears. The flapping wing mechanism is linked to two symmetrical gears. Both gears were attached to the driving linkage in order to transform the rotation motion of the motor to the linear motion, thus moving the wing up and down within the constraint designated flapping angle. Every complete revolution of the motor is equivalent to one complete revolution of driving gear as shown in Figure 2 (a) & (b).



(a) (b)

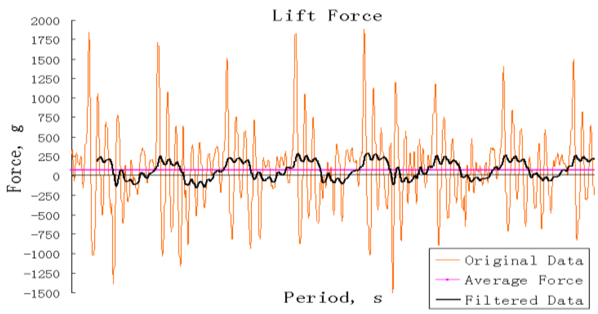
Figure 2: (a) 3-D flapping model design, (b) Kinematic represntation.

The rotation of gears is powered by a 6V DC electrical motor The motor comes with gear ratio of 150:1 and stall torque of 1.1 kg-cm. This motor was selected due to its characteristic, especially high power-to-weight ratio. In order to ensure flapping frequency vs. throttle accuracy, a series of voltages was tested based on equation 1 and the corresponding flapping frequencies were recorded by tachometer.

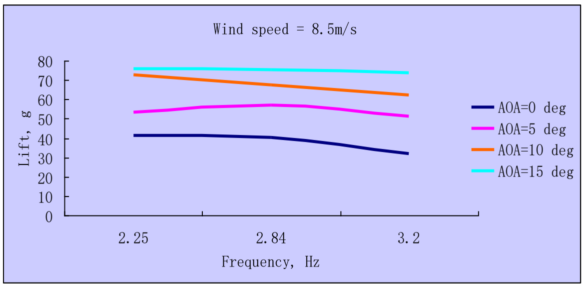
$$Y = 0.7x+2.34 \quad (1)$$

3.0 RESULT AND CONCLUSION

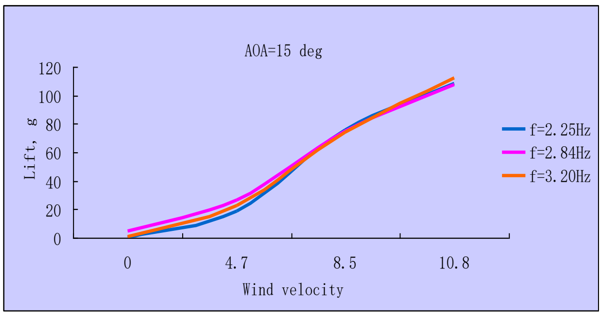
During the flapping cycle, the flapping wing model would exert a certain amount of force to the strain gauge. However, the force registered by the strain gauges was not purely forces causes by the lift generated by flapping motion alone. The measured force by the gauges consists of gravitational, inertial and aerodynamic components. The gravitational force were contributed by the model i.e. mount, body, motor and wing mass. This total force signal was balanced out in the PCD-30A software from the measured force traces. The inertial components represent the acceleration forces on the mass of the wings. The experiment was conducted with three different variables, namely wind velocity, flapping frequency and angle of attack. Data were collected at sampling frequency of 2000Hz for duration of 2.5 seconds. The speeds of the flapping wing model were controlled by adjusting the power supply. The relation between the lift produced and wind speeds at different flapping frequency for a constant angle of attack are shown in Figure 3(b), 3(c) & 3(d). It is observed that the lift force is proportionately increased with the available flapping frequency at all variable wind speeds. The lift continues to rise at the constant rate with the increasing flapping frequencies and wind velocity.



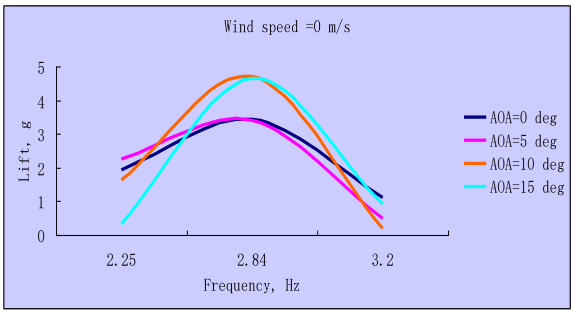
(a)



(b)



(c)



(d)

Figure 3 : (a) Lift force raw data, (b) Lift forces under different flapping frequencies and angles of attack at a wind speed of 0 m/s, (c) Lift forces under different flapping frequencies and angles of attack at a wind speed of 8.5 m/s, (d) Lift forces under different flapping frequencies and wind speeds at an angle of attack of 15°.

It is observed that the higher the wind speed, the higher the aerodynamic lift force generated. Due to the higher flight speed, the free stream air momentum was found increasing and together with the effect of flapping motion, resulting significant lifts force. However, theoretically, the lift approaching the maximum before tremendously decreases at certain frequency just before the resonances occurred. However, due to the motor speed limitation, the maximum flapping frequency is below that the resonance frequency. In addition, due to the motor power constraint, higher frequencies testing were not performed and the maximum available lift of this particular model was undetermined.

From the lift study of this semi-rigid and thick airfoil flapping wing design, the lift production is not strong enough for its body-to-weight ratio. The maximum lift, 112.1g or 1.1N which is available from the testing (AOA=15o, Wind speed=10.8m/s, f=3.20Hz) is not sufficient to lift up the model. The vibrations and frictions of the model at some certain frequencies caused some inconsistencies in lift production. Hence several future-work suggestions were made in order to improve the design i.e. the model may be re-design the model with a thinner airfoil and elastic wing for better lift and thrust production, appropriate elements for moving joints i.e. bearing to avoid vibration, appropriate material selection and internal structure for weight reduction and strength, proper fabrication techniques, bigger motor for higher power, thus flapping frequencies. A detailed CFD analysis would be necessary and useful for future work on flapping wing MAV.

4.0 REFERENCES

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