LIFT AND THRUST CHARACTERISTICS OF THE FLAPPING WING MICRO AIR VEHICLE

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Abstract

This paper concentrates on the effects of the maximum angle of flap and flapping frequency on the thrust and the lift characteristics of the flapping wing micro air vehicle (MAV). A flapping mechanism powered by small D.C motor was designed and fabricated for experimental purpose. It is possible to change the maximum angle of flap and flapping frequency by adjusting the crank size of flapping mechanism and supply voltage to the D.C motor respectively. Experiments were conducted in special micro air vehicle wind tunnel of NPU (Northwestern Polytechnical University). One wing has been used for this experiment to avoid the influence of wing geometry parameter. All the tests were carried out in full-scale model. The result of experiment provides the guidelines in conceptual design and aerodynamic design of flapping wing MAV.

1 Introduction

Micro aerial vehicles (MAVs) have attained a great deal of attention in the past decade due to maturing technologies that have made them feasible and cost-effective. Although the majority of current vehicle concepts rely on fixed wing or rotorcraft [1], flapping wing flight provides superior maneuverability which would be necessary in obstacle avoidance and navigation in small spaces, as demonstrated by biological flying insects. By using flapping wings, the birds and insects effectively increase the Reynolds number without increasing their forward flight speed. Conceivably, the size of an aircraft could be reduced to a size of few millimeters as observed in nature. On the other hand, the propulsion of flapping wing has unique advantage over other type propulsion systems such as generation of lift force and thrust without excessive size or weight [2].

Hence the flapping wing is an efficient/useful option in designing smaller vehicles like the Micro Air Vehicles. It has taken almost one hundred years of development in flapping-wing flight. It seems to have been Knoller in 1909 and Betz in 1912 who first discovered that a flapping wing produces thrust [3]. At Present, there have a lot of investigation on aerodynamic force of flapping wing. At the Naval Postgraduate School, Jones and Platzer investigated propulsion and power-extraction using a two-dimensional unsteady panel method [4]. The problem of flapping wing propulsion has been considered by Liu using vortex lattice and panel methods [5]. The unsteady aerodynamic force effects（Lift and Thrust）on wing design parameters were discussed by A. Muniappan [6].Nevertheless, the investigation is very little on the effect of mechanism parameters on aerodynamic force. The prime objective of this work is to investigate the effect of mechanism parameters viz., the maximum angle of flap and flapping frequency on the development of the aerodynamic force by the wing flapping. These mechanism parameters are common for other types of flapping mechanism. Hence the results of experiment are directly applicable to other types of flapping mechanism.

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2 Mechanism Description

2.1 The crank link mechanism

All the tests were conducted with the flapping mechanism shown in fig. 1. This mechanism is named as crank link mechanism. It comprises three components, which are actuator, linkage system and retardment system. For the entire design, the center of crank disk is considered as the origin. The distance between the right and left wing link joints is called as link distance (w). It is fixed in the whole mechanism. One end of the connecting rod is attached to the crank disk. The other edge of the connecting rod is connected with the wing. Crank disk is attached to a gear shaft, which transfers the running of crank into the flapping action on the other end where the wing is to be attached. When the crank completes one rotation, one flapping cycle would be completed. ALL the connecting rods are made of aluminum-alloy, which have high specific strength and stiffness.The gears are made of plastic, which have not only high stiffness but also very light. The overall mass of the flapping mechanism is 15g.

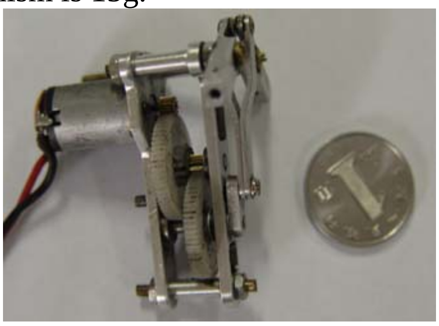

Figure 1: the flapping mechanism

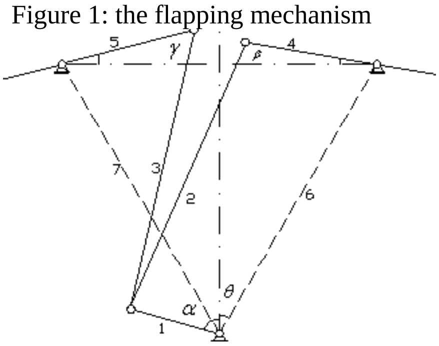

Figure 2: theory figure of flapping mechanism

2.2 Mechanism Design Parameters

1. The maximum angle of flap
2. Crank radius

The maximum angle of flap is given by,

$$\phi = \arccos\frac{l_4^2 + l_6^2 - (l_1 + l_2)^2}{2 l_4 l_6} - \arccos\frac{l_4^2 + l_6^2 - (l_2 - l_1)^2}{2 l_4 l_6} \quad (1)$$

Where l_1 is the radius of crank and l_2 is the length of connecting rod and l_4 is the length of the other connecting rod and l_6 is the distance between wing joint and the center of crank running. In the fig 2 $l_2 = l_3$, $l_4 = l_5$, $l_6 = l_7$. The maximum angle of flap was adjusted by changing the radius of the crank by using the equation (1).

2.3 Wing Lag

The motion of flapping mechanism is unsymmetrical This introduces a lag between the right and the left wings(Fig.3).When the crank circumvolve 90° (the most left position of crank) the lag is as high as 5.61° .As the revolving angle of the crank approaches $n\pi$ (n = 0,1,2…), the lag reduces to 0°. This clearly indicates that the flapping of wing is symmetrical only at the rotation angles $n\pi$ (n = 0,1,2…). The disadvantage is the unequal lift produced by the wings at any instant. This causes flapping motion in the lateral direction. It was proved at later flight tests of prototype.

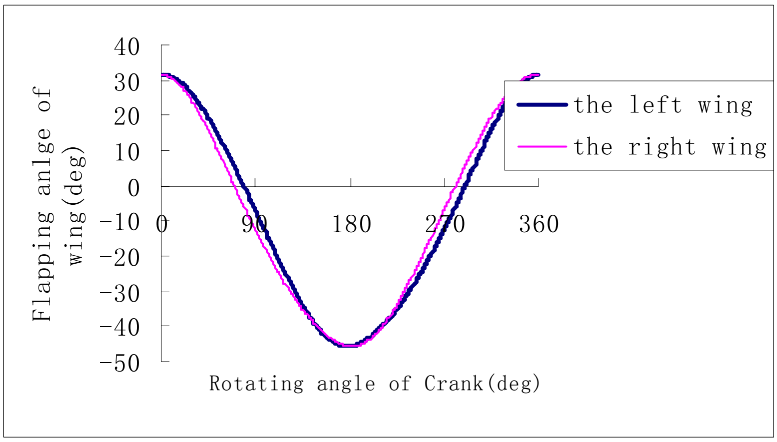

Figure 3: Wing Lag graph

3 Experiment Methodology

The experimental setup is shown in fig.4. The experiments were carried out in a low speed open jet tunnel which having test cross section

50x50 cm^2. The experimental Reynolds numbers were performed at $1.02\times10^4 < Re < 6.9\times10^4$. In the speed range from 4m/s to 10m/s, the average turbulence level was 0.22%.The wing planform used testing is shown in fig.5 which is having an aspect ration of 3.75 and total wing area of 240 cm^2. Same wing are used for all these tests to avoid the influence of wing geometrical parameters. The wing is constructed by using Mylar sheet as a skin and kryptol as a spar. Flat plate airfoil was used for the wing and that eliminates the effect of camber, airfoil shape, thickness etc. The controlling parameters of experiments are the free stream velocity (U) and the flapping frequency (f), the free stream velocity in the test section had been controlled by adjusting the speed of the blower fan. The flapping frequency was controlled by adjusting the input voltage of D.C motor.

A high quality low-speed wind tunnel with velocity uniformity of 0.22% and speeds from 0m/s to 20.3m/s was constructed in NPU(Northwestern Polytechnical University).. The wind tunnel has a 50 cm x50 cm x80cm test section. The precision of experiment is 0.47%. This test setup is shown in Figure4. Wind tunnel tests were conducted to measure lift and Drag produced by the flapping wing. The flapping frequency from 4Hz to10Hz with 1Hz increment was chosen to investigate the change of lift and drag around the flapping frequency. The controlling parameters of experiments are the free stream velocity (U) and the flapping frequency (f), the free stream velocity in the test section had been controlled by adjusting the speed of the blower fan. The flapping frequency was controlled by adjusting the input voltage of D.C motor. The aerodynamic force measurements were taken using low capacity 2-D force loadcell.

Figure 4: The MAV Wind Tunnel of NPU

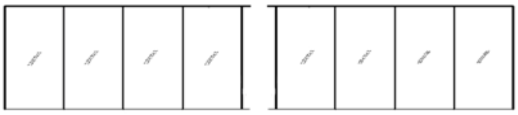

Figure 5: Wing Planform used for testing

To investigate on the effects of the maximum angle of flap and flapping frequency on the aerodynamic characteristics of the flapping wing, four maximum angle of flap were respectively chosen and they are 55°, 75°, 95° and 115°. For each maximum angle of flap experiments were conducted for four different velocities ranges from 4m/s to 10m/s and frequencies ranges from 4 Hz to 8Hz. Twenty experiments were performed for each the maximum angle of flap.

4 Results and Discussions

4.1The results of lift and discussion

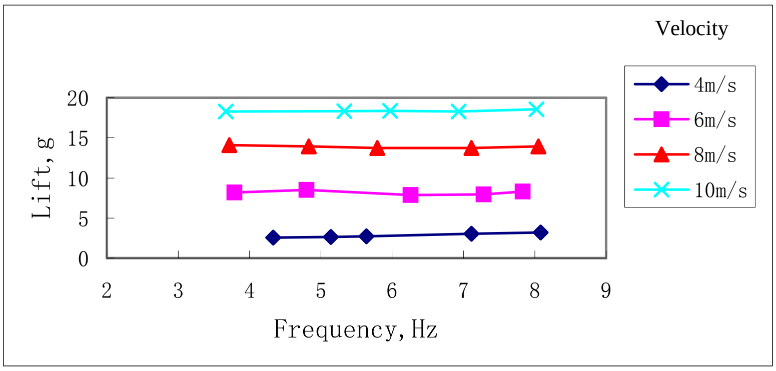

Figure 6(a) : Variation of Lift with flapping frequency at the maximum angle of flap =55º

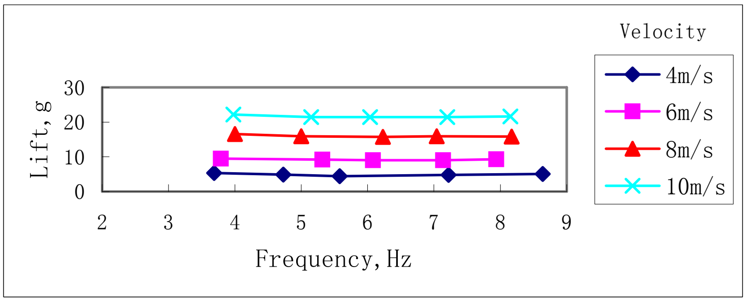

Figure 6(b) Variation of Lift with flapping frequency at the maximum angle of flap =75º

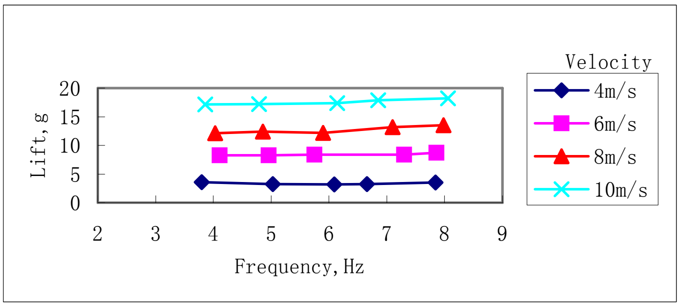

Figure 6(c) Variation of Lift with flapping frequency at the maximum angle of flap =95º

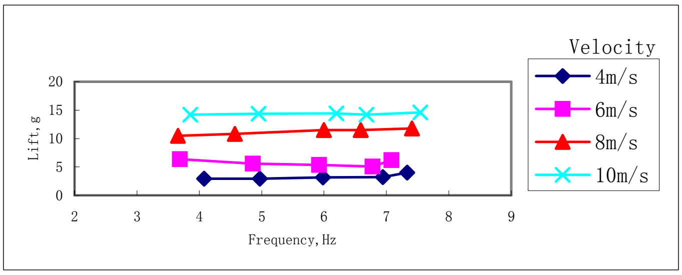

Figure 6(d) Variation of Lift with flapping frequency at the maximum angle of flap =115º

The figures from 6(a) to 6(d) give the variation of lift with free stream velocity and flapping frequency for each maximum angle of flap. The results of experiment indicate that the lift force increases with increase in free stream velocity but the trend seems to be constant with the flapping frequency. It is possible that variation of lift force is primarily relation to angle of wing attack.

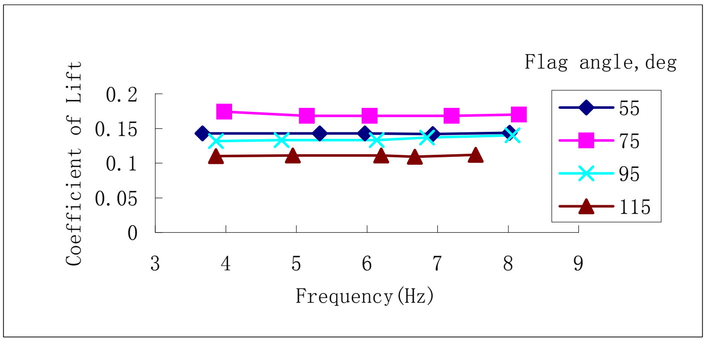

Figure 7(a) Variation of the lift coefficient with the maximum angle of flap at a free stream velocity of 4m/s.

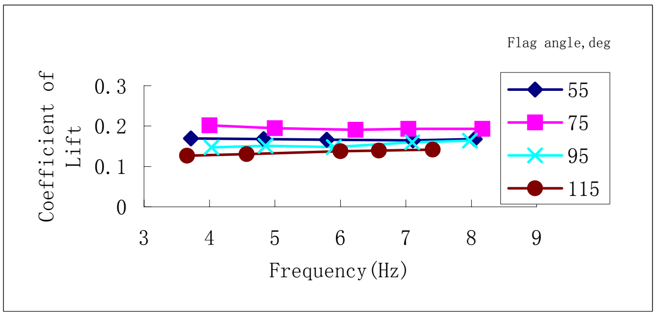

Figure 7(b) Variation of the lift coefficient with the maximum angle of flap at a free stream velocity of 6m/s.

The figure 7(a) and 7(b) shows the variation of lift coefficient with the maximum angle of flap and flapping frequency for a constant free stream velocity. When the maximum angle of flap is 75 degree, the lift coefficient is maximal. The lift coefficient takes second place when the maximum angle of flap is 55 degree or 95degree. The lift coefficient is minimal when the maximum angle of flap is 115 degree.

4.2 The results of thrust and discussion

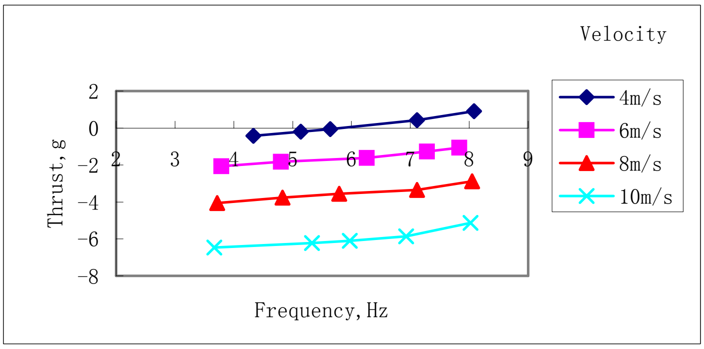

Figure 8(a) Variation of Thrust with flapping frequency at the maximum angle of flap =55º

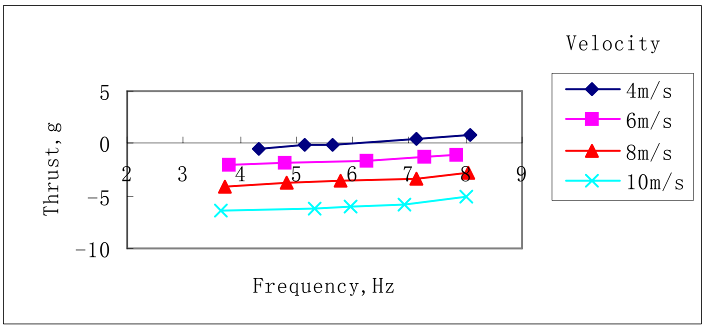

Figure 8(b) Variation of Thrust with flapping frequency at the maximum angle of flap =75º

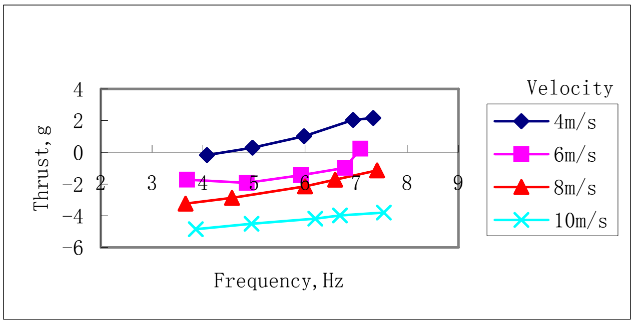

Figure 8(c) Variation of Thrust with flapping frequency at the maximum angle of flap =95°

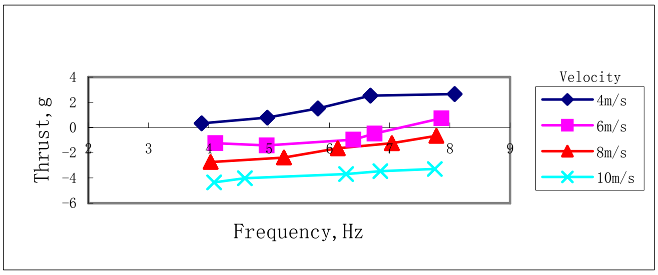

Figure 8(d) Variation of Thrust with flapping frequency at the maximum angle of flap =115°

In this paper, the thrust of flapping wing was the net thrust. It. was defined as subtract drag force from thrust force of flapping wing. The figures from 8(a) to 8(d) gives the variation of thrust with free stream velocity and flapping frequency for each maximum angle of flap. In general, these four graphs indicate that thrust increases with increase in the flapping frequency. The thrust force decreases with increase in free stream velocity. It brings increase of drag due to increase of free stream velocity. Therefore thrust of the flapping wing decreases with increase in free stream velocity.

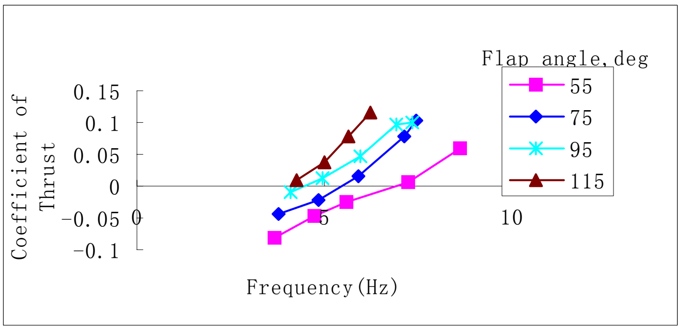

Figure 9(a) Thrust variation with the maximum angle of flap at a free stream velocity of 4m/s.

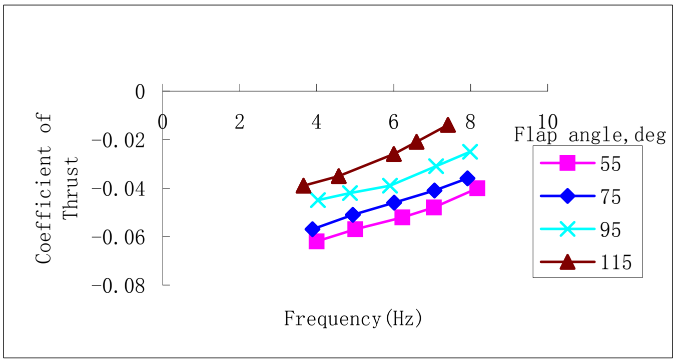

Figure 9(b) Thrust variation with the maximum angle of flap at a free stream velocity of 6m/s.

The figures 9(a) and 9(b) show the variation of thrust with the maximum angle of flap for a constant free stream velocity. The results of experiment show that thrust coefficient increases with increase in the maximum angle of flap. This is partially due to a passive feathering mechanism, but it was also thought that flow separation played an important role in flapping-wing.

5 Conclusion

The effects of different maximum flapping angle and flapping frequency on aerodynamic characteristics of the flapping wing MAV was studied, results from experiments shows that the thrust increase with increase in maximum angles of flap and increase in flapping frequency, but decreases with increase in the free stream velocity. The lift force increases with increase in free stream velocity. The variation of lift is basically constant with increase in flapping frequency. No regime was found in which the bigger of the maximum angles of flap, the better of lift characteristic. It is suggested that there is an optimum the maximum angles of flap for a given flapping frequencies and free stream velocity.

In the present paper, we have presented an overall development of Npu-sentinel including wing design and fabrication, mechanism design and fabrication, wind tunnel test and flight test. The success of the Npu-sentinel prototype proves that the 40 centimeters span micro air vehicle is feasible. With radio control system, the flight duration was significantly longer at 10 minutes.

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