Experimental Study on the Propulsion Performance of the M-shape flapping wing’s bending angle

Jingxian Chen\textsuperscript{a}, Xiaofang Nie\textsuperscript{b,\textasteriskcentered}, Ximing Zhou\textsuperscript{c}

Lilienthal laboratory, Beijing Implant Aircraft Co., Ltd., 6 Chaqian Road, Changping, Beijing, 102200, China

\textsuperscript{a}79834096@qq.com, \textsuperscript{b} *Corresponding author e-mail: 2377811041@qq.com
\textsuperscript{c}930326939@qq.com

Abstract. To study the the effect of flapping wing with different bending angles $\alpha$ on the thrust, in this paper, 9 M-shape flapping wing models with different bending angles, ranging for 0° to 22°, were designed. The rotating arm experiment was adopted to conduct the thrust test on the flapping wing models with different bending angels under the wind speed of 15m/s. The result shows that the span-wise flapping wing’s curvature could rectify the airflow, the proper curvature could prevent the span-wise airflow at the surface the flapping wing and leads the airflow towards backward, the amount of air pushed backwards by the flapping wing is larger, therefore the value of thrust is increased; As well as the rectification of M-shape flapping wing increases the thrust value, the flapping wing’s form drag also increased due to the bending angle. According to the results of the experiment, when the bending angle is less than 12°, the increment of the thrust is larger than the decrease of the form drag, so the thrust value increases gradually. However, when the bending angle is larger than 12°, the increment of the thrust is less than the decrease of the form drag, so the thrust value decreases. The thrust value is the largest when the bending angle is 12°.

1. Introduction

Unlike fixed wing aircraft, the flapping-wing flight could generate both lift and thrust force at the same time. Therefore, domestic and foreign scholars have carried out plenty of theoretical and experimental studies on the mechanism of flapping wing propulsion. By observation of micro structures of feathers from birds with different weight and flight altitude, researchers have found that the three are open, semi-open or closed and gradual contracting nozzles in birds first primaries (Fig.1).During down-stroke, air enters the tubular structure from the plume and is turned to the trailing edge and also accelerated; therefore, a strong thrust is generated [1]. Besides, a wind tunnel test has shown that flapping wings with wing blades could prevent the span-wise airflow beneath the wings (Fig.2), which results in the improvement of the flapping wing’s aerodynamic performance [1].
A flapping wing model with span-wise curvature (Fig. 3) is made by Lilienthal laboratory of Beijing Implant Aircraft Co., Ltd. An air blowing test is carried out with the flapping wing model fluttering. As shown in the result, compared with the planer flapping wing, the airflow of flapping wing with a span-wise curvature is rectified, thus, the velocity vector of the airflow is turned backwards.

In this paper, a large size flapping wing model with span-wise curvature as M-shape is designed (Fig. 4). The cross section of the flapping wings perpendicular to the axis is isosceles triangle (Fig. 5). The sharp angel formed by the hypotenuse and the base of the triangle is defined as the bending angle $\alpha$ of
the flapping wing. Nine M-shape flapping wing models with different bending angles are designed, ranging for 0° to 22°. The aerodynamics test of the flapping wing model was carried out by means of the rotating arm experiment. Through the test, the effect of flapping wing with different bending angles on the average thrust at the speed of 15m/s was studied.

![Figure 4. M-shape flapping wing model (left) and planar flapping wing model(right)](image)

![Figure 5. Sketch of bending angle α](image)

2. Experimental equipment and methodology

In this paper, the aerodynamics test of the flapping wing model was carried out by means of the rotating arm experiment. The equipment is a rotating platform. The rotating platform consists of fixed frame, rotating shaft, rotating power supply circuit and model installation plate (Fig.6). The rotation platform is equipped with a transmission mechanism (Fig.7) which could realize the movement of flapping wings. The transmission mechanism is equipped with a crank slider structure and driven by a 1kw motor. The crank slider could drive the flapping rod reciprocating up and down to achieve the flapping of the flapping wings. A cantilever is fixed on the installation plane of the rotation platform, and a 3kw motor-driven propeller is installed on the cantilever.

![Figure 6. Rotation Platform](image)  ![Figure 7. Transmission Structure](image)
The installation plane of the propeller is in the rotating direction perpendicular to the rotating direction of the platform. The 3kw motor is powered by a DC power supply through a rotating circuit on the rotation platform. After the propeller is started, the thrust generated by the propeller would drive the platform to rotate. The speed of the propeller could be regulated by the remote control. By changing the thrust of the propeller, the speed of the rotation platform could be controlled. The experimental flapping wings are installed on the flapping structure of the flapping wings, rotating along with the platform. And the wings achieve forward movement while flapping in order to simulate the straight-line flight of flapping wings.

One flapping wing model was respectively placed on the flapping wing rods of both sides. The placement position of the model was 1.35m away from the center of the shaft. The two flapping wing models were the same, with consistent installation direction with the platform rotation direction. The thrust was positively correlated to the platform rotation rate. The greater the rotation rate was, the greater the thrust would be. The line speed of the sector mounting point was defined as the inlet velocity. Through calculation, the line speed of the sector mounting point would reach 106r/min, when the platform speed was 15m/s. During the experiment, the flapping wing was made to flap at the frequency of 2.5Hz first, to drive the platform rotate. And then, the remote control was used to make the propeller driving the platform to accelerate to \( \omega_0 = 106 \text{r/min} \). The propeller speed was kept unchanged, and the flapping of the flapping wings was stopped. In this case, the platform speed became \( \omega_1 \), with the speed change \( \Delta \omega (\Delta \omega = \omega_0 - \omega_1) \) namely the action quantity on the platform rotating speed when the flapping wing was flapping at the speed of 15m/s.

\[
F_T = F_w + F_H = F_D \\
(1)
\]

\[
F_w = F_D - F_H \\
(2)
\]

In the formula, \( F_T \) is the thrust, \( F_D \) is the aerodynamic drag, \( F_H \) is the force onto the platform applied by the propeller, and \( F_w \) is the force on the platform applied by the flapping wing. The greater \( \Delta \omega \) is, the larger \( F_w \) will be. That means, the thrust generated by the flapping of the flapping wing will reach the maximum when \( F_w \) is 15m/s.

The experimental air speed was set at 15m/s, namely, the platform speed was 106r/min. The arm length of the flapping wing was 0.8 meters, the installation angle was 0°, the flapping frequency was 2.5Hz, and the flapping angle was 45°.

3. Experimental results and analysis

The effect of the flutter of the M-shape flapping wings with different bending angle on the platform rotating speed at the wind speed of 15m/s was obtained through the rotation platform experiment. The experimental data are as shown in Tab. 1.

**Table 1. Experiment Data**

| Bending angle(°) | Flapping Wing + Propeller Platform Rotation rate/(r·min⁻¹) | Platform rotation rate after Flapping Stops/(r·min⁻¹) | Change of rotation rate/(r·min⁻¹) |
|-----------------|----------------------------------------------------------|---------------------------------|-------------------------------|
| 0               | 105.805                                                  | 101.971                         | 3.834                         |
| 7               | 105.986                                                  | 101.830                         | 4.156                         |
| 10              | 106.204                                                  | 101.580                         | 4.624                         |
| 12              | 106.188                                                  | 99.776                          | 6.412                         |
| 15              | 105.593                                                  | 100.577                         | 5.016                         |
| 17              | 106.000                                                  | 101.546                         | 4.455                         |
| 18              | 106.311                                                  | 101.926                         | 4.385                         |
| 20              | 106.652                                                  | 102.093                         | 4.559                         |
| 22              | 105.962                                                  | 101.468                         | 4.494                         |
Fig. 8 shows that the with the augment of M-shape flapping wing’s bending angle, the value of thrust force increases first, and then decreases with the augment of the bending angle. On the one hand, the span-wise flapping wing’s curvature could rectify the airflow; a proper curvature could prevent the span-wise airflow at the surface the flapping wing and leads the airflow towards backward, the amount of air pushed backwards by the flapping wing is then larger, therefore the value of thrust is increased. On the other hand, flexible deformation exists during flapping wing’s flutter. The flexible deformation produces thrust as well as resistance. With the increase of the bending angle, the area of flapping wing increases, which leads to the increase of airfoil shape resistance. According to the experiment’s results, when the bending angle is less than 12°, the increment of thrust caused by the curvature’s rectification is larger than the increment of resistant; thus the thrust of the flapping wing increase gradually. However, when the bending angle is larger than 12°, the increment of thrust caused by the curvature’s rectification is smaller than the increment of resistant; therefore, the thrust of the flapping wing decreases gradually.

Figure 8. The relationship between thrust value and M shape flapping wing’s bending angle.

Figure 9. Path line of planar flapping wing (left) and M-shape flapping wing (right).
4. Conclusion

In this paper, 9 M-shape flapping wing models with different bending angles, ranging for 0° to 22°, were designed. The rotating arm experiment was adopted to conduct the thrust test on the flapping wing models with different bending angels, ranging from 0° to 22°, and the following conclusion and inference have been drawn:

(1) The span-wise flapping wing’s curvature could rectify the airflow; the proper curvature could prevent the span-wise airflow at the surface the flapping wing and leads the airflow towards backward, the amount of air pushed backwards by the flapping wing is larger, therefore the value of thrust is increased.

(2) As well as the rectification of M-shape flapping wing increases the thrust value, the flapping wing’s form drag also increased due to the bending angle. According to the results of the experiment, when the bending angle is less than 12°, the increment of the thrust is larger than the decrease of the form drag, so the thrust value increases gradually. However, when the bending angle is larger than 12°, the increment of the thrust is less than the decrease of the form drag, so the thrust value decreases. The thrust value is the largest when the bending angle is 12°.

References

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