The design and analysis of flapping wing mechanism based on eccentric crank slider

Shuze Wang[†], Zeyu Wang[*, †], Xintong Huang[†]

Department of aerospace engineering, Nanjing University of Aeronautics and Astronautics, Nanjing, China

* Corresponding Author Email: zaizaiyijin@gmail.com

[†]These authors contributed equally.

Abstract. In order to improve the sharp return characteristics of the flutter mechanism, and then increase the downward power of the flutter aircraft, reduce the drag of the wing upward, and increase the flight efficiency, this paper designs a flutter drive mechanism with sharp return characteristics based on the eccentric crank slider flutter structure. Firstly, the kinematic model of the eccentric crank slider mechanism is established through motion analysis, and then the simulation model of the flutter mechanism is established in SOLIDWORKS to simulate its motion and verify its theoretical analysis. The results show that the designed flutter mechanism has an upper limit angle of 17°, a lower limit angle of -34°, and a travel speed ratio of 1.35, which are consistent with the flight parameters of the selected bionic bird, so it has good aerodynamic performance. And the kinematic parameters obtained from the simulation are consistent with the theoretical calculation, which verifies the correctness of the theoretical calculation.

Keywords: Flutter wing configuration; eccentric crank slider mechanism; kinematic analysis; SOLIDWORKS.

1. Introduction

In recent years, flapping wing aircraft have gradually been more and more widely developed and applied. Flutter planes can be seen in military and civil fields. The design idea of flutter aircraft is mainly derived from birds. Flutter planes have many advantages such as low power consumption, stability, maneuverability, and stealth. [1][2].

The main flapping mechanism of the wing aircraft is mainly divided into the two-degree-of-freedom flapping-wing mechanism of insects and the single-degree-of-freedom flapping-wing mechanism of birds. The forward propulsion and the speed difference between the up and down of the flapping wing and the upward lift generated by the wing itself. At present, the structure of the flapping wing is roughly two-dimensional single crank double rocker mechanism, double crank double rocker mechanism, crank slider Mechanisms, etc. Three-dimensional space crank-rocker mechanism, space RURS mechanism, etc. For the unfavorable factors such as heavy weight, complex structure, and poor stability of the multi-degree-of-freedom flapper, the improvement of the flapper is a total of three parts: (1) Simplify the flapping wing mechanism. (2) Increase the quick-return characteristic (3) Optimize the rod length attribute.

Domestic Longhuan Ruan, Yu Hou et al. designed a two-degree-of-freedom bionic flutter flying robot with a single motor drive to realize the coupled motion of two degrees of freedom of flutter and twist, which makes the wing form closer to birds [3], but the mechanism is more complex, decreasing the reliability and increasing the weight. In China, Yicun Xu and Guanghua Zong analyzed the reasons for the asymmetry of the crank rocker flutter mechanism [4], and thus made improvements to the asymmetry. In addition, Yang Yonggang and Su Hanping have made a multi-degree-of-freedom aerodynamic simulation of a bird-like flutter vehicle, which can provide theoretical and technical support for the development and improvement of the flutter vehicle [5]. Domestic Longhuan Ruan analyzed the motion characteristics of the flutter wing configuration and obtained the variation laws of angular displacement, angular acceleration, etc. for torsion and flutter. Luo Kun, Guo Xiangying, and Zhang Wei from Beijing Institute of Technology in China designed a simple and compact structure to realize a single motor-driven double flutter wing [6], and established a simulation model of the whole micro flutter wing vehicle in ADAMS, and the simulation obtained the angular velocity graphs, displacement graphs, and force graphs at the joints of the two flutter wings under the dynamic state. Chen Yuanhang et al. investigated the correlation between the Strohal number and spatial asymmetry and flutter angle of attack in single-degree-of-freedom flutter aircraft and six small bird flutter planes in level flight, and derived a mathematical analytical model and performed experimental verification [7].

Currently, most single-degree-of-freedom flutter configurations ignore the actual conditions of bird flight, and it is found that the down-flap phase of the wings is the main phase of lift generation during bird flight. And this phase accounts for a large proportion of the whole flutter cycle. [8] However, most of the current single-degree-of-freedom flutter mechanisms do not take into account the quick-return characteristics of the flutter motion.

Therefore, considering the sharp return characteristics of flutter motion, this paper proposes an eccentric crank slider mechanism by analyzing the foundation of two-dimensional crank rocker mechanism based on improving the mechanism configuration and optimizing the rod length, without increasing the energy dissipation of each component and the load condition of the flutter mechanism, while solving the problem of low efficiency caused by the lack of difference between the flutter up and down flutter speed [8], so as to improve the overall flutter This can improve the overall aerodynamics and stability of the flutter plane, which can further meet the needs of small and medium-sized flutter planes.

2. Comparative analysis of institutions

2.1. Planar flapping wing structure

The two-dimensional single-crank rocker structure is shown in Figure 1 as a simple four-bar mechanism, which has been widely used, but because the structure is designed as a single-crank structure as the driving part, it produces asymmetry in the process of flapping wings, which has a certain impact on stability. [10] Under this premise, optimizing the influence of aerodynamics when this instability brings about flapping wings is proposed to the crank slider mechanism as shown in Figure 2, in order to save space and reduce the pressure angle, it is changed to the optimal design of the mechanism structure as shown in Figure 3. In order to realize the quick-return characteristic, increase the downward speed, and improve the flight efficiency, the crank slider mechanism is biased as shown in Figure 4.

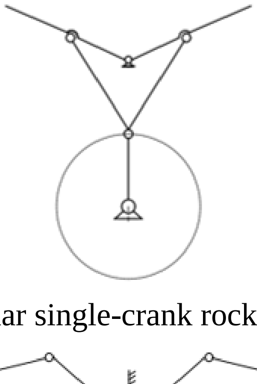

Figure 1. Planar single-crank rocker mechanism.

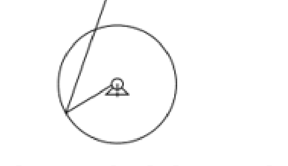

Figure 2. Flat crank slider mechanism.

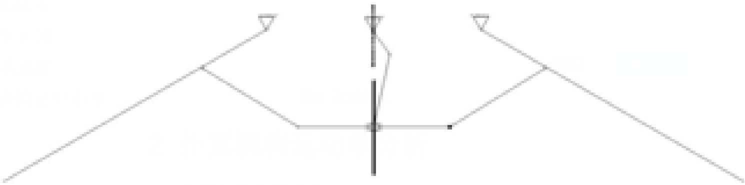

Figure 3. Improved structure.

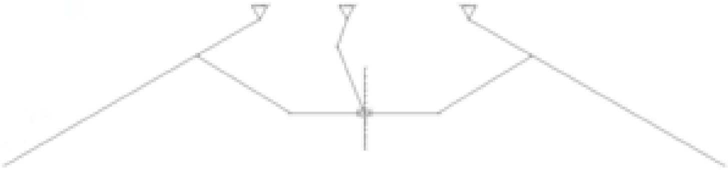

Figure 4. Offset slide-crank mechanism.

3. Kinematic analysis of flapping wing mechanism

3.1. Theoretical analysis of kinematics of flapping wing mechanism

The mechanism can be adapted to the flight characteristics of birds by changing the eccentric distance e to change the sprint characteristics of the mechanism. By changing the length of each rod, the motion characteristics of the fluttering rod can be changed, so the length of the rod must be designed to meet the flight characteristics of the bird. Since the two inclined crank rocker mechanisms are symmetrical about the vertical plane, the left side of the mechanism is chosen as an example for the convenience of the study object. In order to make the fluttering motion more close to the oscillation of the bird's wing, the components and the total mechanism need to choose reasonable geometric parameters, selected: e=209.9,l_1=200,l_2=500,l_3 =516.5,l_4=400,l_5=500,d=23.6, Figure 5 shows the left half of the eccentric crank rocker slider mechanism, where the angle at which the crank turns is , which is called the input angle θ_1.The angle of the flapping wing swing is φ, which is called the output swing angle.

According to the left half of the eccentric crank rocker slider mechanism in Figure 5, set the distance between node D and node F l_{DF} to list the geometric relationship between the relevant members of the mechanism:

$$l_1\cos\theta_1 + e = l_2\sin\theta_2 \tag{1}$$

$$C = e + d - l_3 \tag{2}$$

$${l_{DF}}^2 = C^2 + (l_1\sin\theta_1 + l_2\cos\theta_2)^2 \tag{3}$$

By solving the equations (1), (2), and (3), get the geometric relationship between φ and θ

$$\varphi = 180° - \arccos\left(\frac{C}{l_{DF}}\right) - \arccos\left(\frac{{l_5}^2 + {l_{DF}}^2 - {l_4}^2}{2l_5 l_{DF}}\right) \tag{4}$$

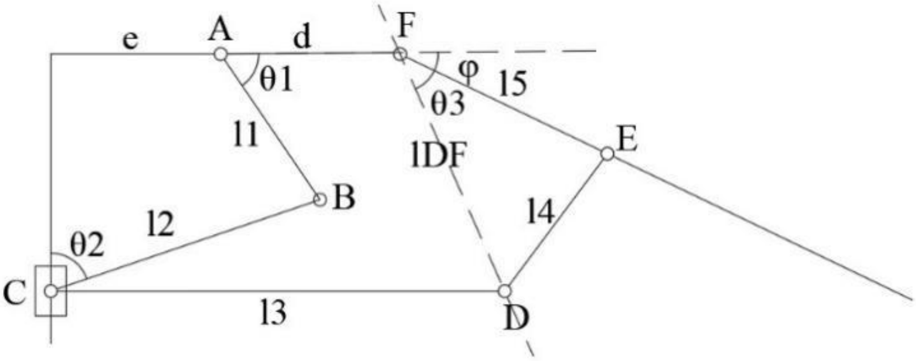

Figure 5. The left half of the eccentric crank rocker slider mechanism.

3.2. Calculation of flutter angle θ

The geometric parameters of this mechanism are substituted into Equation (4), the angular velocity of the crank is taken as a fixed value, the angular velocity refers to the biological fluttering frequency selection $\omega=\pi$ rad/s, and the time in one cycle is obtained by MATLAB solving the curve t and the input angle φ are shown in Figure 6.

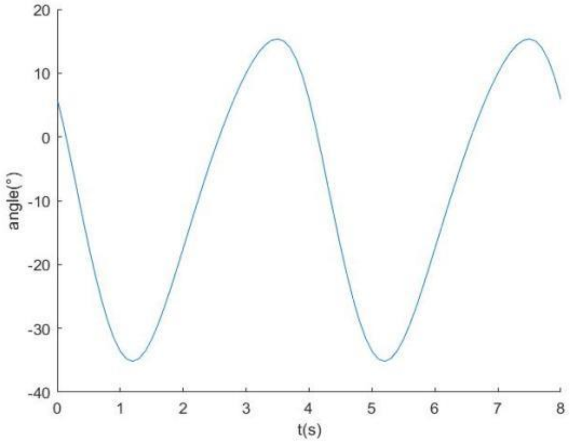

Figure 6. Relationship between time and flutter angle.

From the relationship graph, it can be concluded that the upper and lower fluttering limit angles of this flapping wing mechanism are$\varphi_{on} = 17°$, $\varphi_{down} = -34°$and the travel velocity-ratio coefficient is 1.35.

3.3. Calculation of w fluttering angular velocity

For the sake of research characteristics, we consider the input angular velocity as a fixed value, and the input angle is proportional to the time, satisfying:

$$\varphi = wt \tag{5}$$

Equations (1), (2), (3), and (4) are connected to obtain the equation of output swing angle with φrespect to time, and the first derivative of t the equation with respect to time, t that is, the fluttering angular velocity w_1.

The fluttering angular velocity is derived, and the angular velocity of the fluttering mechanism is obtained:

$$(\varphi)' = \omega_1 = \left(-\frac{C}{C^2+B^2}+E\right)(F+G) \tag{6}$$

Thereinto:

$$B = l_1\sin\theta_1 + l_2\cos\theta_2,\ C = e + d - l_3,\ E = \frac{1}{\sqrt{1-\cos^2\theta_3}}\frac{B^3+2C^2B-Bl_{DF}}{2l_5{l_{DF}}^3}; \tag{7}$$

$$F = \omega l_1\cos\theta_1, G = \frac{2el_1w\sin\theta_1+{l_1}^2w\sin2\theta_1}{2\sqrt{{l_2}^2-{l_1}^2\cos^2\theta_1-2el_1\cos\theta_1-e^2}} \tag{8}$$

From this, we obtain the relationship between fluttering angular velocity ω and time, substitute the parameters of the t mechanism into the formula, and use MATLAB to solve the curve of fluttering angular velocity, as shown in Figure 8. From the theoretical formula and the fluttering angular velocity curve diagram, it can be obtained that the maximum angular velocity of the upper and lower fluttering of this mechanism is $\omega_{down} = 32°/s$ respectively, and $\omega_{down} = -48°/s$. We can compare Figure 7: in one cycle of fluttering, the angular velocity of the fluttering member is continuously slowed down until it is zero; the acceleration from the lower limit position to the zero degree position is constantly increasing. Reach maximum in a certain position, and then slow down.

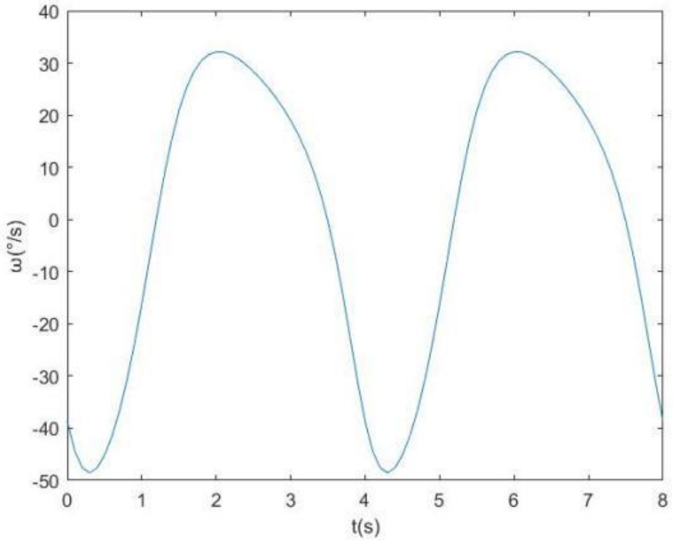

Figure 7. Fluttering angular velocity curve.

At the same time, it can be seen from Figure 7 that the angular velocity image is smooth and smooth, and no sharp corners appear, which means that the speed has not undergone a sudden change, and the transmission performance of the mechanism is good[9].

4. Solidworks simulation analysis

In order to verify the correctness of the theoretical analysis, based on the above theoretical analysis and mechanism diagram design of the eccentric crank slider mechanism, we establish a 3D model of the flapping wing aircraft with the help of SOLIDWORKS, including frame, eccentric crank slider mechanism, flutter rod, etc. This is shown in Figure 8.

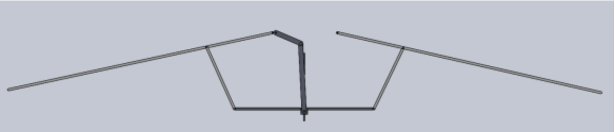

Figure 8. SolidWorks model.

The flapping limit of the flapping wing mechanism is shown in Figure 9, and the flapping limit of the lower flapping wing mechanism is shown in Figure 10.

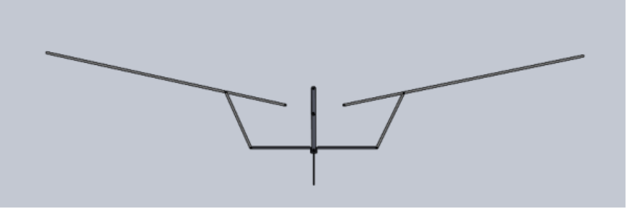

Figure 9. Upper limit position.

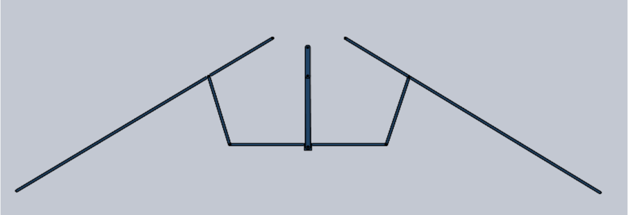

Figure 10. Lower limit position.

The motion module of SOLIDWORKS is used to analyze the kinematics of the model, so as to obtain the parameters of the swing rod and verify the correctness of the theoretical calculation with simulation.

Through SOLIDWORKS motion analysis, the angle between the flapping wing rod and the ground (Figure 11) as well as the angular velocity (Figure 12) and angular acceleration (Figure 13) at each moment can be obtained.

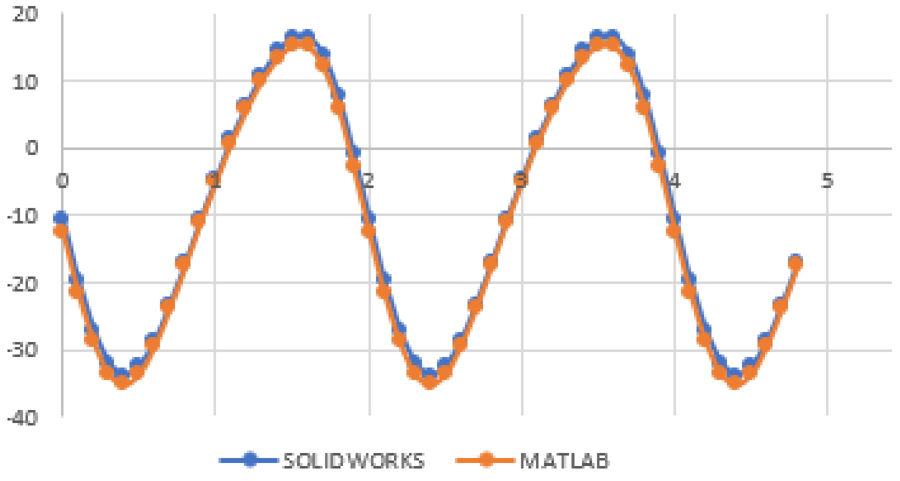

Figure 11. SolidWorks angular displacement and time image.

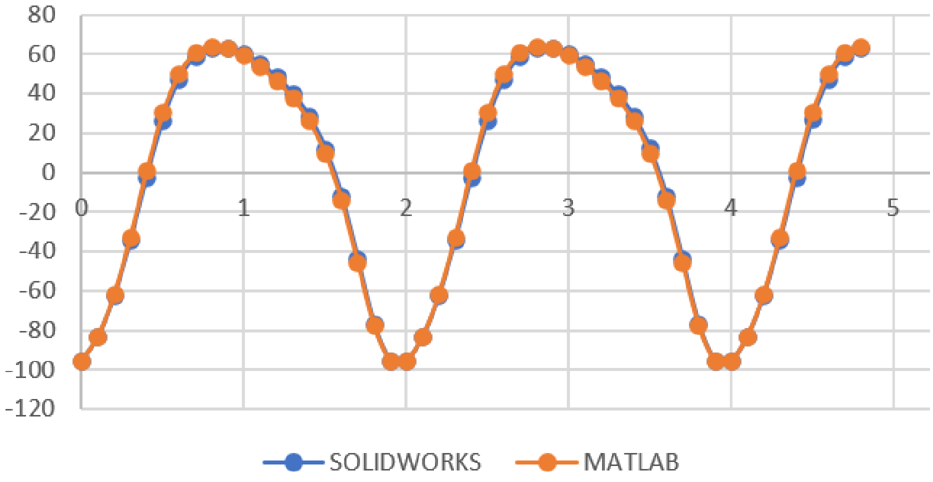

Figure 12. SolidWorks angular velocity and time image.

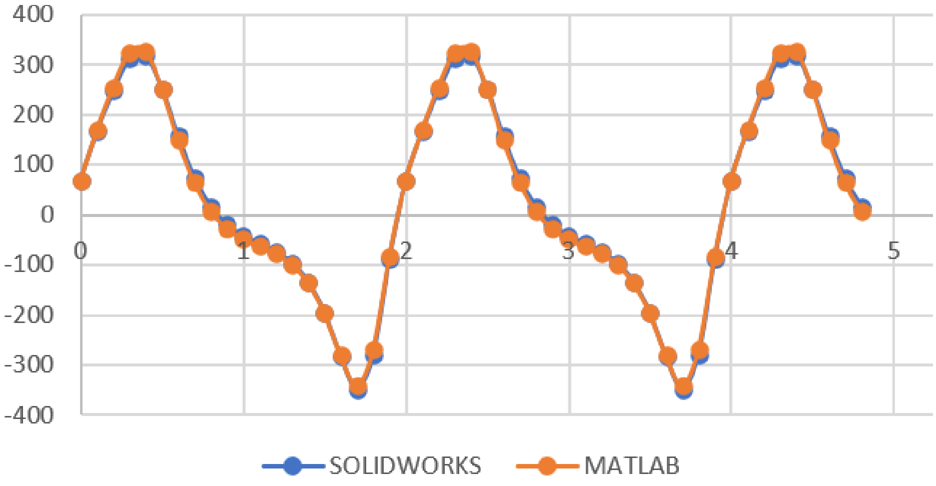

Figure 13. SolidWorks angular acceleration and time image.

By comparing the above figure with Figure (6), (7), we can conclude that the theoretical analysis of the mechanism is basically consistent with the motion simulation results. It can be seen from the simulation data that the limit angular acceleration of the mechanism is very small, which is conducive to the stability of the mechanism. The Agency is therefore a realistic improvement of the existing flapping wing aircraft, taking into account the actual situation.

This section verifies that the changes in angle, angular velocity, and angular acceleration of the flapping rod are consistent with the theoretical analysis by using SOLIDWORKS software modeling to dynamically simulate the flapping wing mechanism.

5. Conclusion

(1) The upper limit of the flapping wing mechanism is 17° and the lower limit is -34° during the flapping process, which is consistent with the flight parameters of the selected birds and has good aerodynamic performance.

(2) SOLIDWORKS was used to simulate and analyze the designed flapping wing mechanism, and the SOLIDWORKS simulation analysis curve of the joystick flutter angle was consistent with the MATLAB theoretical calculation and analysis curve, which verified the correctness of the theoretical analysis.

In this paper, the problem of low efficiency and upper and lower limits of flapping wing aircraft is solved by designing a crank rocker mechanism with quick-return characteristics. This paper establishes mathematical models of input angle and output angle relationship, angular velocity and angular acceleration, which provides a design basis for subsequent in-depth research on the mechanism.

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