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Study on Aerodynamic Characteristics of Flapping Wings Motion Mode

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Abstract. Flapping Wing Micro Aerial Vehicle (FWMAV) is a new type of MAV simulating the flight of insects or birds. FWMAV can generate lift and thrust simultaneously to achieve the function of lifting, forward flying or hovering by only flapping wings. It also can change flight mode flexibility by adjusting flapping parameters, which makes it have nice maneuverability and high flight efficiency and more suitable for military mission. So it has great development and research value. In this paper, insect is selected as biomimetic research object, using the computational fluid dynamics method to make a numerical study on aerodynamic characteristics of flapping wings motion mode.

1. Introduction

At present, most of the numerical studies on flapping wing aerodynamic characteristics of bionic flapping-wing micro air vehicles are carried out under a single and specific "8" flapping trajectory [1][2][3]. However, the "8" shaped flutter of different insects in nature is different from that of flying insects. Therefore, it is of great significance to further analyze the differences of aerodynamic characteristics between different types of flapping trajectories and different states of the same type, and to provide a solid theoretical basis for the design of flapping-wing micro air vehicles with complex motions. In this chapter, the X-Flow software based on lattice Boltzmann method is used to calculate the different symmetrical "8" flapping trajectories of rigid model wings by increasing the degree of freedom of motion in the absence of free inflow. The differences of aerodynamic characteristics are analyzed, and the influence of different flapping wing modes on aerodynamic forces is explored [4][5].

2. .The Influence of Horizontal Symmetry "8" Shaped Flapping Wing on its Aerodynamic Characteristics

The kinematic functions of the horizontal "8" flapping wing mode are as follows:

Flutter angle around OX axis (First down and back up):

$$\psi(t) = -0.5\Phi cos(2\pi ft) \tag{1}$$

The twist angle corresponding to the OZ axis in one cycle:

$$\alpha(t)=\begin{cases}(\pi-\alpha_d)-\theta((t+0.125T)-\frac{t_r}{2\pi}sin(\frac{2\pi(t+0.125T)}{t_r})) & 0\le t<0.125T\\ \alpha_d & 0.125T\le t<0.375T\\ \alpha_d+\theta((t-0.375T)-\frac{t_r}{2\pi}sin(\frac{2\pi(t-0.375T)}{t_r})) & 0.375T\le t<0.625T\\ \pi-\alpha_d & 0.625T\le t<0.875T\\ (\pi-\alpha_d)-\theta((t-0.875T)-\frac{t_r}{2\pi}sin(\frac{2\pi(t-0.875T)}{t_r})) & 0.875T\le t<T\end{cases} \quad (2)$$

In the above equation, Φ is the flutter amplitude, take Φ=120°,f for flutter frequency, take f=10Hz, $\alpha_d$is the middle angle of the lower swing, and α_d=40°, t_r is reverse time and take t_r=0.25T, $\theta=(\pi-2\alpha_d)/t_r$.

The variation of flutter angle and twist angle with time in one motion cycle is shown in Figure 1. It can be seen from the diagram that the torsion angle is fixed at the middle of the attack. At the end of the flutter up, the model wings begin to flip and the twist angle decreases until the first quarter of the swoop, and the twist angle decreases to a fixed value. The flapping rule of downward flapping is similar to that at the end. Under this motion function, the projection of the wing tip trajectory on the XY plane is shown in Figure 2:

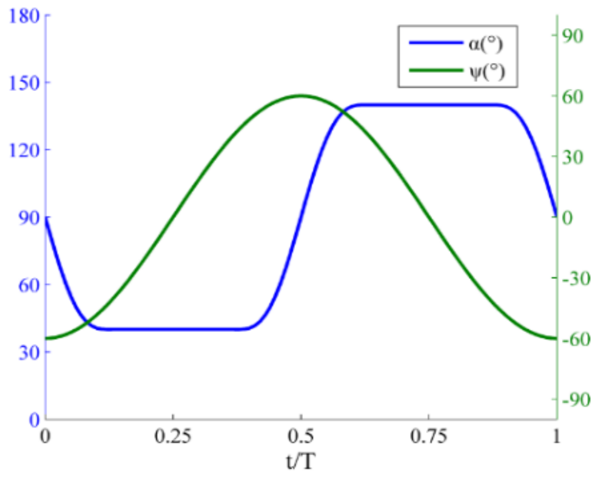


Figure 1. Angle of flutter and twist of horizontal symmetry "8"

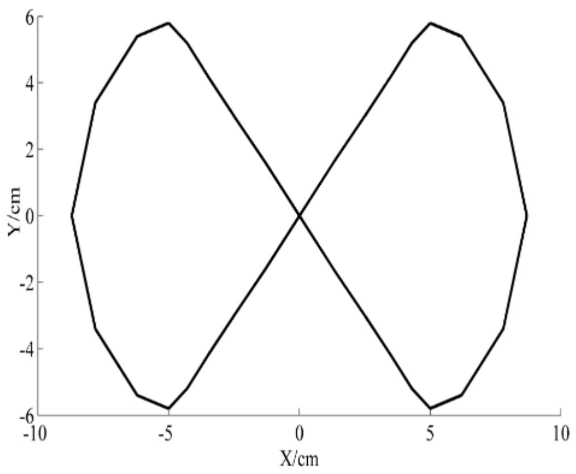


Figure 2. Projection of wingtip trajectory in XY plane

The numerical results of lift coefficient and drag coefficient varying with time in a motion cycle are shown in Figure 3 below:

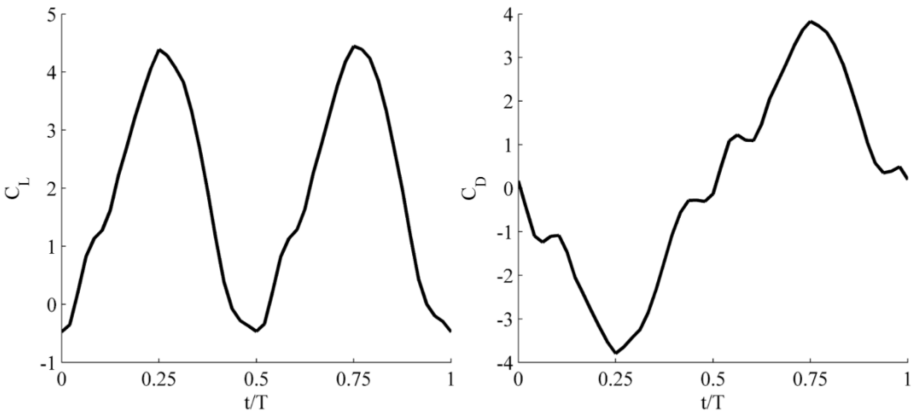
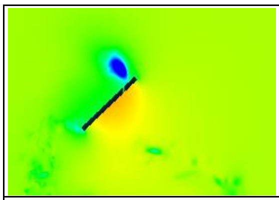
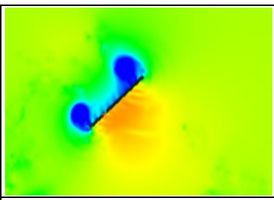
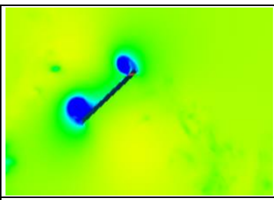
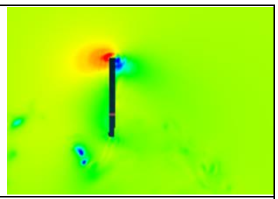
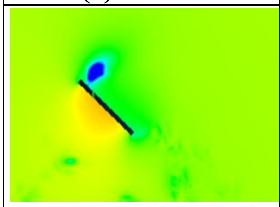
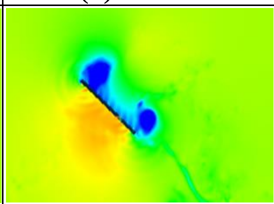
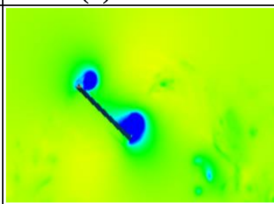
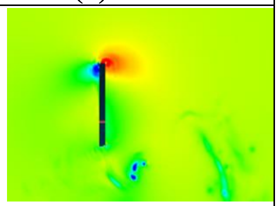


Figure 3. C_L and C_D of model flapping in horizontal "8" flutter mode (Negative resistance is thrust.)

In order to explore more intuitively the change of aerodynamic force in the campaign cycle under the flutter mode, the pressure cloud chart of the extension section of the model wing 1/2 at different times is shown in Table 1:

Table 1. pressure cloud chart of 1/2 horizontal section "8" shape at different times

			
(a)1/8time	(b)2/8time	(c)3/8time	(d)4/8time
			
(e)5/8time	(f)6/8time	(g)7/8time	(h)8/8time

Based on the cross section pressure cloud chart and aerodynamic coefficient map at different time points, we can draw the following conclusions: During the upstroke and down stroke of the horizontal symmetrical "8" flapping wing in the next movement cycle, the pressure at the lower end of the wing is always greater than that at the upper end, and the lift force is generated. This is due to the existence of twisting motion, when fluttering down the direction of the movement of the wings is downward and backward and When fluttering upward the direction of the movement of the wings is forward and downward. At the same time, due to the torsion movement, the effective area of the model wing with air contact is reduced. The peak value of lift coefficient is less than that of linear flapping wing. However, due to the symmetrical motion trajectory of the downward and upward flutters, the thrust produced by the downward dive is equal to the resistance produced by the upward flutter, so that the average thrust coefficient is 0 in a movement cycle. Therefore, this type of flutter is suitable for takeoff flight or hovering flight.

3. The Effect Of Vertical Symmetry "8" Shaped Flapping Wing on its Aerodynamic Characteristics

The kinematic functions of the horizontal "8" flapping wing mode are as follows:

Flutter angle around OX axis (First down and back up):

$$\psi(t) = -0.5\Phi cos(2\pi f t) \tag{3}$$

A twist angle around a OZ axis in a cycle:

$$\alpha(t) = \begin{cases} \alpha_d \sin(\frac{\pi t}{t_r}) & 0 \le t < 0.2T \\ \alpha_d & 0.2T \le t < 0.3T \\ \alpha_d \cos(\frac{\pi(t-0.3T)}{t_r}) & 0.3T \le t < 0.7T \\ -\alpha_d & 0.7T \le t < 0.8T \\ -\alpha_d \cos(\frac{\pi(t-0.8T)}{t_r}) & 0.8T \le t < T \end{cases} \tag{4}$$

In the above equation, Φ is the flutter amplitude, take Φ=120°, f for flutter frequency, take f=10Hz, $\alpha_d$is the middle angle of the lower swing, and α_d=45°, t_r is reverse time and take t_r=0.4T.

The variation of flutter angle and twist angle with time in one motion cycle is shown in Figure 4. It can be seen from the diagram that the variation law of the torsion angle of the motion mode is similar that of the horizontal symmetrical "8" flapping wing. In the middle of the downward flutter and upward flutter, the twist angle is set. At the end of the flutter up, the model wings begin to turn over, and the twist angle decreases until the middle of the flutter, and the twist angle decreases to a fixed value. The flapping rule of downward flapping is similar that at the end. Under this motion function, the projection of the wing tip trajectory on the XY plane is shown in Figure 5:

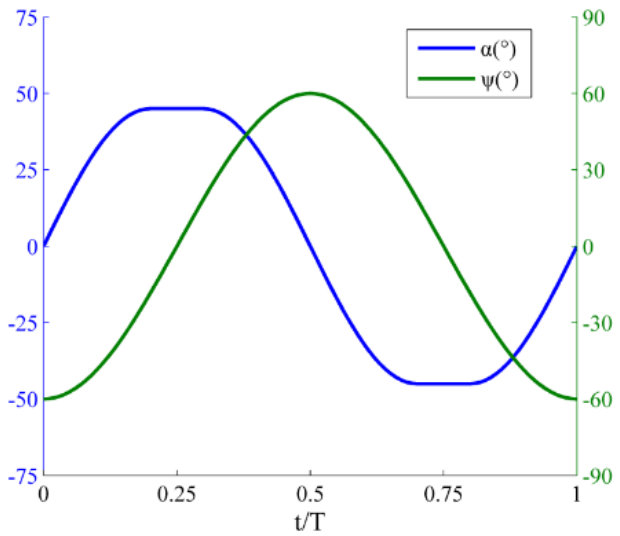


Figure 4. angle of flutter and twist of vertical symmetry "8"

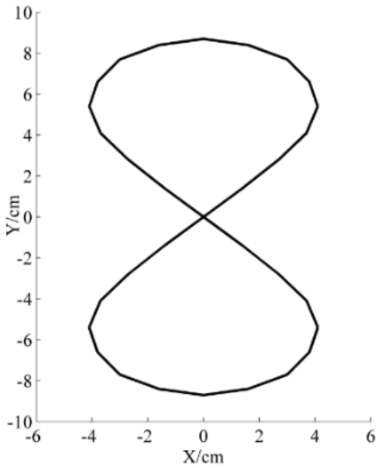


Figure 5. Projection of wingtip trajectory in XY plane

The numerical results of the time-dependent variations of lift and drag coefficients during a period of motion are shown in Figure 6 below:

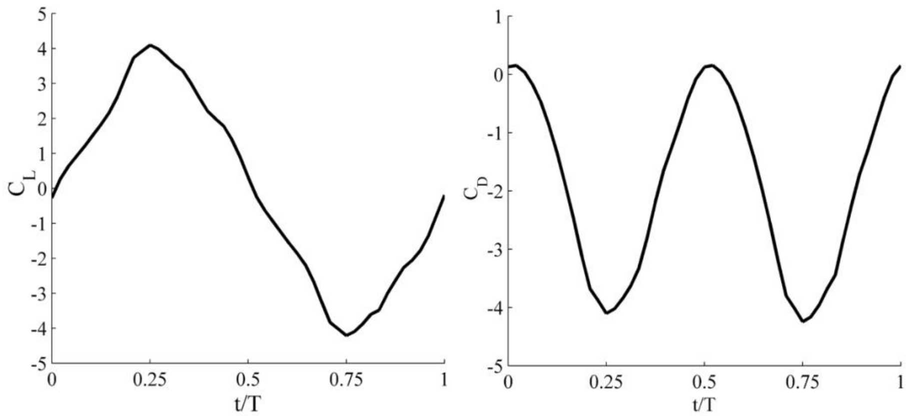
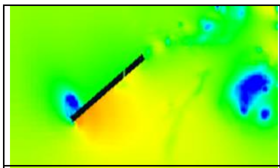
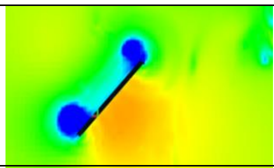
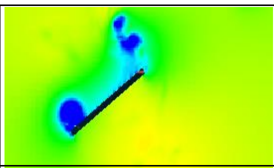
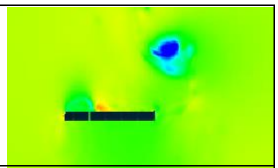
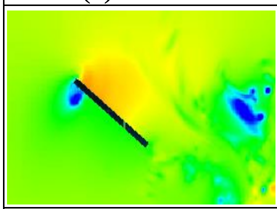
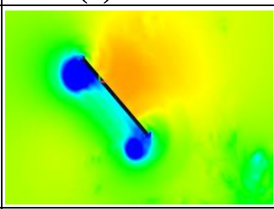
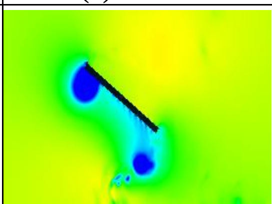
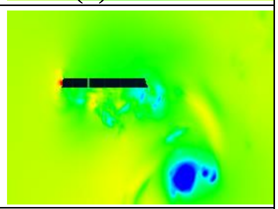


Figure 6. C_L and C_D of the vertical "8" flutter model wings. (Negative resistance is thrust)

For a more intuitive study of the aerodynamic changes in the next cycle of the flutter, the pressure the cloud chart at the 1/2 extension of the model wing at different times are shown in Table 2 below.

Table 2. pressure cloud chart of 1/2 vertical section of "8" shape at different times

			
(a)1/8time	(b)2/8time	(c)3/8time	(d)4/8time
			
(e)5/8time	(f)6/8time	(g)7/8time	(h)8/8time

Based on the cross section pressure cloud chart and aerodynamic coefficient map at different time points, we can draw the following conclusions: During the upstroke and downstroke of the vertical symmetrical "8" flapping wing in the next movement cycle, the pressure at the rear end of the wing is always greater than that of the front section, and there is negative resistance (i.e. thrust). This is due to the existence of twisting motion, when fluttering down the direction of the movement of the wings is downward and backward and when fluttering upward the direction of the movement of the wings is upward and backward. However, due to the symmetry of the downward and upward motions, the downward motions produce the same lift and the upward motions produce the same negative lift, so that the average lift coefficient is 0. Therefore, the flutter mode is suitable for the diving acceleration flight state in a short time.

4. Conclusion

In this paper, the following conclusions can be drawn from the numerical study of computational fluid dynamics. The symmetrical "8" shape flutter can produce larger periodic lift than the pure linear flutter. The horizontal symmetry "8" shaped flapping wing is suitable for take-off or hovering flight. The vertical symmetry "8" shaped flapping wing is suitable for diving acceleration flight in a short time. The periodic average aerodynamic force produced by the symmetrical "8" zigzag motion (two degrees of freedom) with flutter and torsion is related to the inclination of the "8" zigzag motion. The inclination angle increases, the average lift decreases, and the average thrust increases. Therefore, by adjusting the size of α_m and α_n properly, different aerodynamic effects can be produced.

Acknowledgments

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