Experimental Research on Flight Patterns of Bees

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***Abstract*--For the research on the bees flight, the experimental platform combined of smoke wind tunnel and high speed camera has been set up. The information of bees flight on the plane can be synchronously recorded by two high speed cameras. By the analysis of pixel coordinates of bees wings on the photographs, the changing rules of wings in the space can be obtained with the establishment of bees space coordinates system. As a result, the changing rules of position angle and stroke angle can also be obtained. With the analysis, we have found that the duration of up-flapping is different with that of down-flapping. During the terminal stage, the wings accelerate quickly. During the period when down-flapping turns into up-flapping, the wings rotation takes part of the duration. And during the rotation, the stroke angle scarcely changes.**

Keywords-honeybee; stroke angle; position angle

I INTRODUCTION

There are many advantages in bees flying. And plenty of aerodynamicists have been focusing on the bees flight. In the early 1960s, Weis-fogh[1] began the research on the bees flight. Sane and Dickison[2] [3] studied the aerodynamic characteristics of flapping flight with mechanical bionic flapping wings. Birch and Dickison [4] studied the wake effect of flapping flight by the use of mechanical flapping wings. Ellington[5] [6] summed up insects flight rules including insects body feature and wings track during flight by one high speed camera. The calculation method of Ellington by use of only one high speed camera is complicated and too many restricting factors affect the calculation results. In this paper, two high speed cameras with fixed angle have been used. The wings track is calculated by projection relationship of straight line and plane. Compared with other insects, bees have advantage in small volume, flexible motion and easy to catch. So, bees are chosen as the experimental research object. And to capture the bees wings track and get the meticulous changing rules of bees flapping, the bees are belayed.

II EXPERIMENTAL PLATFORM

The experimental platform is shown in Fig. 1. The frame rate of the high speed camera 1 and 2 is 10000 fps. The exposure time is 90μs. The picture resolution is 528×400pixel. Additional extension tube with 85mm camera lens is used in high speed camera. Two high speed cameras are used for the experiment. One is fixed right above the wind tunnel and another is fixed right ahead of the wind tunnel. Two LED lights placed in diagonal direction of the wind tunnel experimental section are optical source.

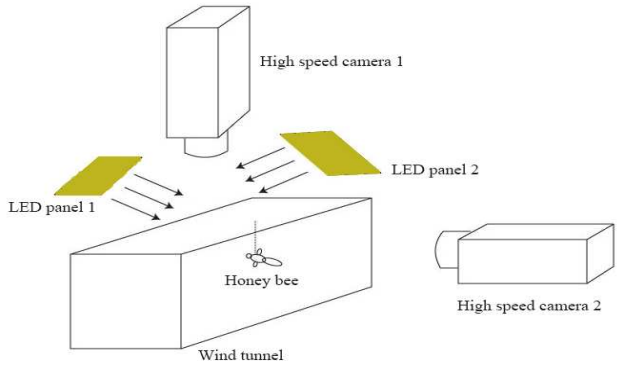

FIGURE I. PHOTOGRAPH OF THE EXPERIMENTAL PLATFORM.

III PROJECTION RELATIONSHIP OF STRAIGHT LINE AND PLANE

During the bees flying, two high speed cameras that separately film plane A and plane B record the information synchronously, as shown in Fig. 2. High speed camera 1 films the horizontal plane, plane A, from the top of the wind tunnel. And high speed camera 2 films the plane B perpendicular to plane A, from the front of the wind tunnel.

During the experiment, bees are fixed. And bees body position can be adjusted by the steel wire that fix the bees. The direction of bees body is parallel to the flow direction of wind tunnel.

In the experiment, we can get features pixel point of bees body. The bees head is set as point A and the bees tail is set as point B. The pixel coordinates on plane A of point A and point B can be used for calculation the throw distance. The throw distance PaQa can be calculated as follow:

$$PaQa=AaBa\times\frac{\sqrt{(Pai\text{-}Pai)^2+(Paj\text{-}Paj)^2}}{\sqrt{(Aai\text{-}Aai)^2+(Aaj\text{-}Aaj)^2}}=AB\times\frac{\sqrt{(Pai\text{-}Pai)^2+(Paj\text{-}Paj)^2}}{\sqrt{(Aai\text{-}Aai)^2+(Aaj\text{-}Aaj)^2}} \quad (1)$$

Where projection point on the plane of point A and point B is Aa and Ba. The pixel point coordinates is (Aai, Aaj) and (Bai, Baj). The actual distance from A to B is AB. The projector distance on plane A is AaBa. And The actual distance AB is 16mm.

The angle between bees body and horizontal plane is δ. On the plane B, projection point of point A and point B is Ab and Bb and The projector distance of line AB on plane B is AbBb. Where AbBb=AB×cosδ.

On the plane B, the projection point of point P and point Q is Pb and Qb. The pixel point coordinates of projection point Ab, Bb, Pb and Qb are (Abi, Abj), (Bbi, Bbj), (Pbi, Pbj)

and (Qbi, Qbj). the projector distance on plane A of line PQ is PbQb:

$$\text{PbQb}=\text{AbBb}\times\frac{\sqrt{(\text{Pb}i\text{-Pb}i)^2+(\text{Pb}j\text{-Pb}j)^2}}{\sqrt{(\text{Ab}i\text{-Ab}i)^2+(\text{Ab}j\text{-Ab}j)^2}}=\text{AB}\times\cos\delta\times\frac{\sqrt{(\text{Pb}i\text{-Pb}i)^2+(\text{Pb}j\text{-Pb}j)^2}}{\sqrt{(\text{Ab}i\text{-Ab}i)^2+(\text{Ab}j\text{-Ab}j)^2}} \quad (2)$$

According to the projection relationship of line and plane, we can get the angle between line PQ and plane A, B. The angle is η_1 and η_2.

$$\begin{cases}\cos\eta_1=\dfrac{\text{PaQa}}{\text{PQ}}\\ \cos\eta_2=\dfrac{\text{PbQb}}{\text{PQ}}\end{cases} \quad (3)$$

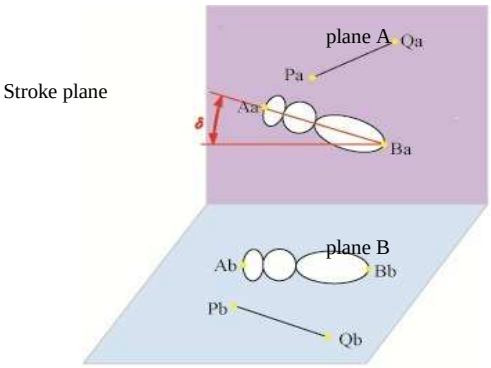

FIGURE II. SCHEMATIC DIAGRAM OF CAMERA PLANE.

IV THE BEE COORDINATE SYSTEM

Because the bees are fixed, the bees flapping motion can be approximately assumed as rigid body rotation around a fixed point. The bees flapping process includes the properties of the rigid motion and the characteristics of the flexible deformation. In the study of the flying of insects and birds, the wings flapping is track is approximately restricted in one plane with the verification of lots of experiment results. The angle that the wings sweep on the stroke plane is called stroke angle. The root point of left wing in the space is defined as point O. Because the bees are fixed, the position of point A remains unchanged. The coordinate system with origin at the root point of bees wing has been built, as shown in Fig. 3. OXYZ is inertial coordinate system. XY plane which is parallel to plane b is horizontal plane. And Y axis is perpendicular to plane A. Plane XZ is parallel to the plane A. Oxyz is stroke plane coordinate system for bees. Oxy is stroke plane. The angle between stroke plane and horizontal plane XY is β.

The Y axis coincides with y axis.

The coordinate transformation from coordinate system OXYZ to coordinate system oxyz is shown in formula (4).

$$\begin{cases}x=X\cos\beta-Z\sin\beta\\ y=Y\\ z=X\sin\beta+Z\cos\beta\end{cases} \quad (4)$$

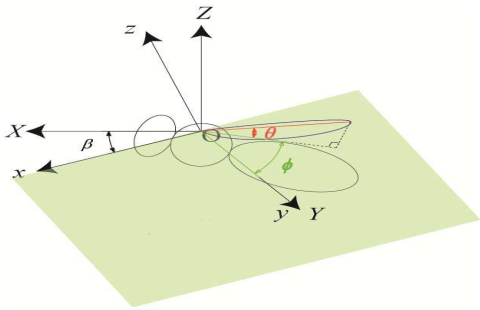

FIGURE III. COORDINATE SYSTEM FOR BEES.

Projection figure of bees on plane OXZ (plane A) is shown in Fig. 4. The body contour of bees is illustrated by red lines. The yellow points represent the projection point of wings tip C on plane XZ in one flapping period. The connection of projection point of point C in one period forms the wing tip track. The blue line is the down-flapping track and the black line is the up-flapping track. The angle between projection on stroke plane and y axis is φ. The line from the top point of up-flapping Sa to the bottom point Ra is line A. And the angle between line 1 and horizontal plane is β. The numerical value of angle β can be obtained by pixel point coordinates (Sai, Saj) and pixel point coordinates (Rai, Raj).

$$\beta=\arctan\left(\left|\frac{\text{Sa}j-\text{Ra}j}{\text{Sa}i-\text{Ra}i}\right|\right) \quad (5)$$

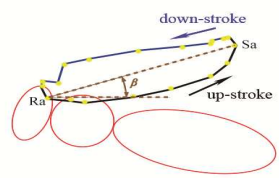

FIGURE IV. SKETCH MAP OF BEES STROKE PLANE ANGLE.

The bee wing tip is point C. The distance OC from wing tip point to wing root point is the length of wing. And the length of wing l=9.8mm. Wing tip position C changes with bees flapping motion in one flapping period, as well as the pixel point coordinates where point C projects on plane A and plane B. By the analysis of the photo shoot by high speed camera, we can get the pixel point coordinates where point O and point C project on plane OXZ and plane OXY. And we can get the angle η_{c1} between line OC and plane OXZ, as well as the angle η_{c2} between line OC and plane OXY. Angle η_{c3} is assumed as the angle between line OC and plane OXZ. The angle η_{c3} can be calculated as following:

$$\sin^2\eta_{c1}+\sin^2\eta_{c2}+\sin^2\eta_{c3}=1 \quad (6)$$

The wing tip point C on the plane OXYZ can be get from the length of OC and angle η_{c1}, η_{c2}, η_{c3}.

$$\begin{cases}X_c=l\sin\eta_{c1}\\ Y_c=l\sin\eta_{c2}\\ Z_c=l\sin\eta_{c3}\end{cases} \quad (7)$$

In formula (7), the coordinate value is only algebraic value. Positive or negative of algebraic value should be determined by projection pixel point coordinates of point C.

With formula (4) and (7), coordinate on coordinate system Oxyz of wing tip point C can be calculated. The angle of amplitude Φ can be calculated with formula (8):

$$\tan\phi = -\frac{x_c}{y_c} \qquad (8)$$

The angle θ between line OC and stroke plane can be calculated with formula (9):

$$\tan\theta = \frac{z_c}{\sqrt{x_c^{\ 2} + y_c^{\ 2}}} \qquad (9)$$

V POSITION ANGLE AND STROKE ANGLE

Fig. 5 shows the changing curve of stroke angle and position angle in three periods. The variation range of bees position angle is 0~30°. The stroke angle in one period is approximate sine curve. Fig. 6 shows the stroke angle in one period. And when down-flapping turns into up-flapping in one period, the rotation of wing takes some time. During the time, stroke angle changes few. As shown in Fig.5 and Fig.6, the maximum amplitude of bees wings flapping is about 110°. Compared with 120° in Ellington's research, 110° is less because the bees in experiment are fixed.

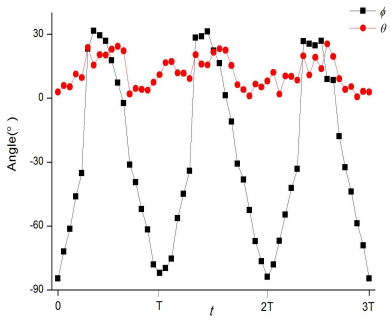

FIGURE V. CURVE GRAPH OF STROKE ANGLE AND POSITION ANGLE IN THREE PERIODS.

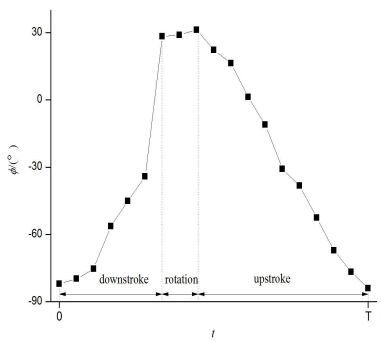

FIGURE VI. CURVE GRAPH OF STROKE ANGLE IN ONE PERIODS.

VI CONCLUSION

In this paper, the kinematics coordinate system of bees is established. Two high speed cameras used to record the flapping information synchronously from two different visual angles are applied in the experiment for kinematics regularity of bees flapping. And the bees flapping are periodic. The variation range of position angle is about 30°. Cycle regularity is not obvious. The variation of Stoke angle is approximate sine curve. And the up-flapping time is bigger than down-flapping time. During the metaphase between down-flapping and up flapping, there is one rotation stage. The wings rotate without flapping during the rotation stage.

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