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Experimental study of wing shape and kinematic effects on aerodynamic performance of a dragonfly

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Abstract

The forewing and the hindwing of a dragonfly have different geometry that could be an evolutionary specialization for better aerodynamic performance. In order to investigate the consequences on the aerodynamics of wings, that have different shape, PIV experiment is conducted. It is debated whether the pitching motion of a dragonfly wing is only induced passively by aerodynamic and inertial forces or some of the pitching are consciously actuated. To reveal the extent of active pitching, the flow fields of the actively actuated wing of the living dragonfly were compared with the flow fields of the same wing artificially actuated only by flapping motion. The results show that different wing shape affect the trailing edge vortex dynamics substantially in case of active pitching, however no substantial effect was observed when no active pitching was present. These results suggests that active pitching adopted by the dragonfly flight that relates to some extent to the wing shape allowing dragonfly to achieve better aerodynamic performance.

1 Introduction

Natural flyers like dragonfly has attracted a lot attention and been studied by many researchers (Shyy, W. 2007). Both wing geometry and kinematics are critical parameters that influence its aerodynamic performance. For the wing geometry study, aspect ratio (AR) and wing shape are most commonly used as parameters (Fu, J. J. 2008, Shyy, W. 2013). Ten wing shapes based on a fruit fly's wing are studied and it is reported a less than 5% difference in the instantaneous lift coefficient (C_L) (G. Luo 2005). In another study, it is found that at different Re number and wing kinematic, the best shapes in terms of efficiency is different (T. Canchi 2012). For the wing kinematic study, a comprehensive measurements of dragonfly kinematics, including wing stroke plane, wing flapping frequency and phase relation between the forewings and hindwings is conducted (Wakeling J M 1997) and it shows that the maximum lift coefficients of dragonflies can reach 1.15, which is greater than those of most other insects (Wakeling J M 1997). The wing kinematics of a dragonfly during a climbing flight is filmed and by using a local circulation method to evaluate the aerodynamic characteristics, it is found that most of the vertical force was generated during the downstroke (Azuma A 1985). It is known that for certain insects (Dickinson, M. H. 1993) use active control over their wing pitching, however it is debated how relevant active pitching is for dragonfly flight (Bergou A J 2007). This study aims to clarify the importance of active pitching and its relation to the different wing shape of forewing and hindwing of a dragonfly.

2 Methods

Time resolved particle image velocimetry was used to aid quantitative data analysis. During the in-vivo experiment, the specimen's abdomen was glued on the edge of a transparent glass. A precision stage was used to hold the glass and to control precisely the position of the measurement cross section. Fig. 1 shows the experiment set up. A possible inter-wing interaction effect could result in altered flow structures and dynamic shape deformation of the wings (Hefler, C. 2017). To isolate our investigation from such effect we have conducted the experiments with one wing gently cut off from the specimen.

Immediately after the in-vivo experiment, the fresh wing was cut down from the joint of the dragonfly body and fixed on a rigid beam (3mm from the axis of rotation) driven by a servo motor. The motor was controlled to flap the wing at the same flapping frequency and with the same amplitude as the specimen did in the previous flow measurement. No active pitching control on the wing was provided by the motor. Again, the motor was mounted on a precision stage. The flow fields at different cross sections of the wing were measured.

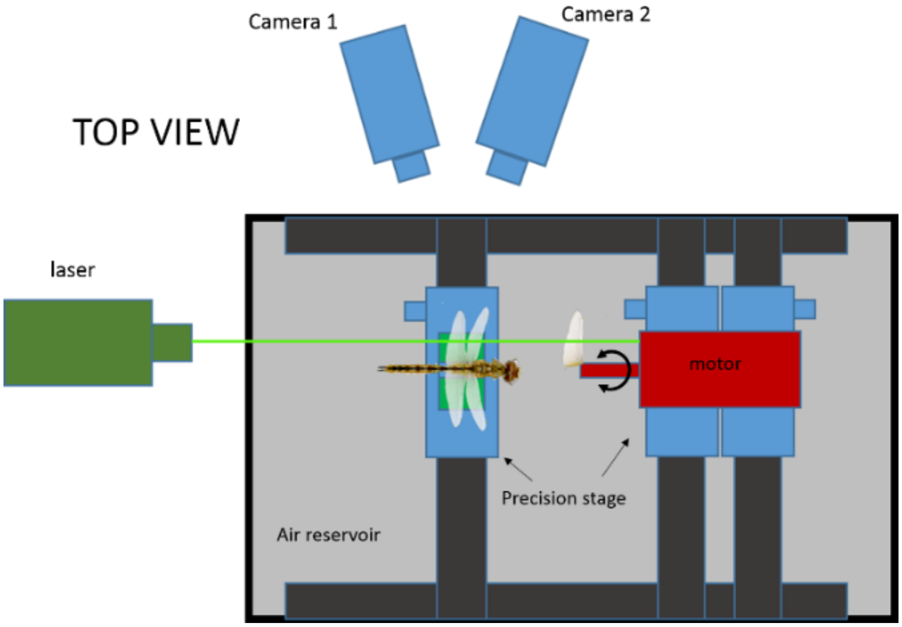


Fig.1 Experiment setup.

3 Results and discussions

The chordwise length of seven different cross sections are measured for both hindwing and forewing. The chordwise length of the wing is defined as the cross section from the leading edge to the trailing edge parallel to the body. Fig. 2 shows the chordwise length of hindwing and forewing. At the root area (5mm away from the body), the chordwise length of hindwing is 2.2 times that of forewing. The chord length of the forewing reaches its maximum around its mid-span, while the hindwing chord gradually decreases to the wing tip.

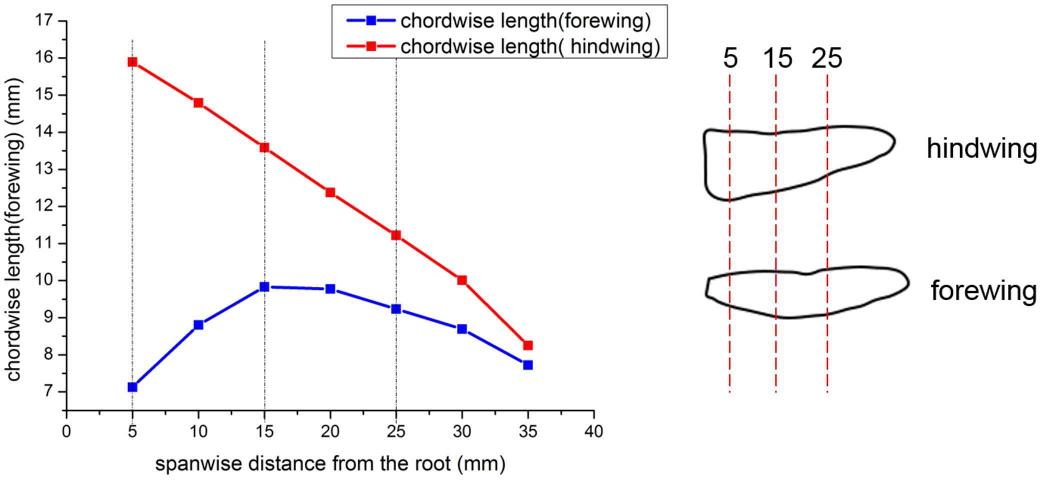
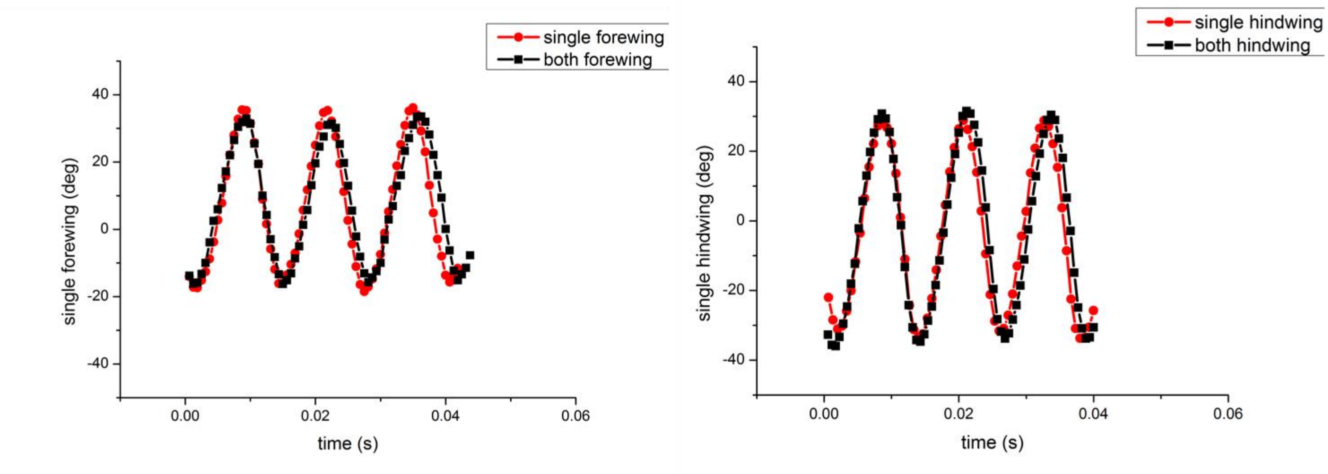


Fig.2 Chordwise length of the forewing and hindwing.

The flapping motion of both wings in single and tandem operation for live specimens were measured. The pterostigma of the wing was used as the tracking point (Fig. 3). We found that the wing removal did not affect the flapping motion of the dragonfly.



(a) (b)

Fig.3 (a) The flapping motion comparison of single forewing and both wing.
(b) The flapping motion comparison of single hindwing and both wing.

Fig.4 shows average velocity v_x and vorticity of a single forewing and a single hindwing of a live dragonfly at the root area (5mm away from the body), where the chordwise length of hindwing is 2.2 times that of forewing. The x axis is defined as the body line of the specimen. Due to the larger chordwise length and because the pitching axis is close to the leading edge, the trailing edge region of the hindwing translates substantially more than the forewings. This results stronger vertical structures shed by the hindwing (Fig.4). It also results in stronger downstream momentum generation.

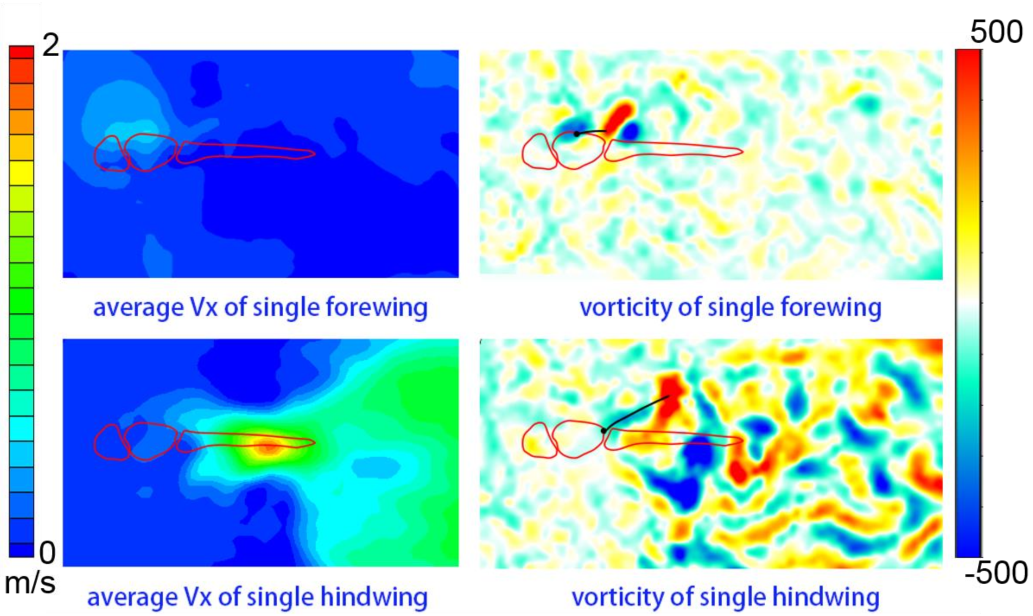


Fig.4 average velocity v_x and vorticity of single wing case
(5mm away from the body for living specimen)

Fig.5 shows average velocity v_x and vorticity of a single forewing and a single hindwing in mechanically actuated flapping. Compared to the results in Fig.4, it is found that the pitching angle of the motor controlled case is much smaller. It also results in much less induced downstream momentum. Comparing Fig.4 and Fig.5, we observed that taken out the active pitching the difference between the aerodynamics of forewing and hindwing becomes less pronounced.

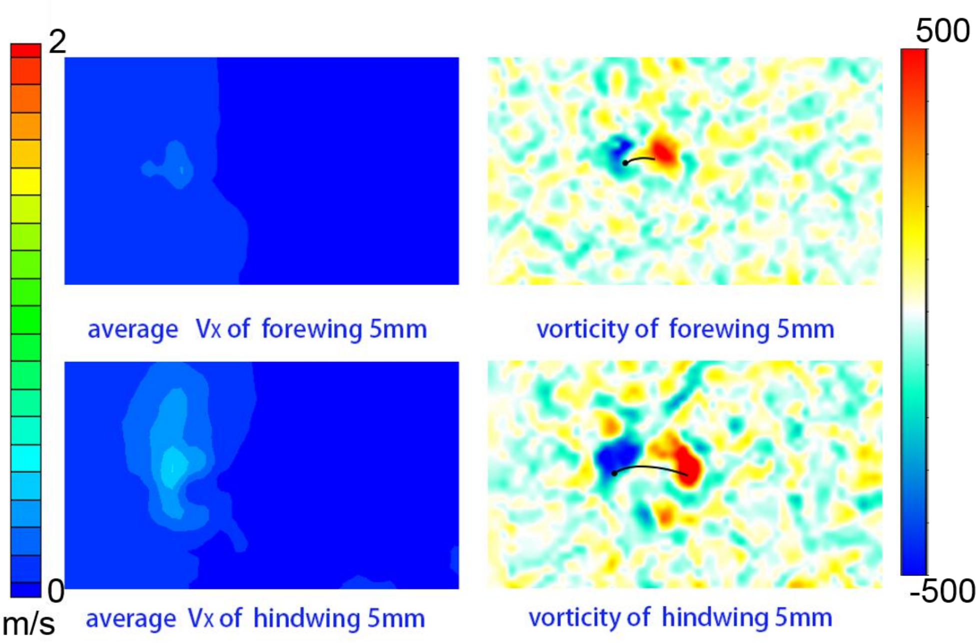


Fig.5 average velocity v_x and vorticity of single wing case
(5mm away from the body in mechanically actuated flapping)

4 Conclusion

It is found dragonfly applies both active and passive pitching. In the root region, where hindwing chord is substantially larger than the forewing's, the active pitching influences the aerodynamics of the wing strongly. When the pitching is only passive, the difference between the forewing and hindwing aerodynamics (trailing edge vortex strength and downstream momentum) is less.

Acknowledgements

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References

Shyy W, Lian Y, Tang J, et al. Aerodynamics of low Reynolds number flyers[M]. Cambridge University Press, 2007.

Fu, J. J., Liu, X. H., Shyy, W., & Qiu, H. H. (2018). Effects of flexibility and aspect ratio on the aerodynamic performance of flapping wings. *Bioinspiration & Biomimetics. 13(3)*

Shyy, W., Aono, H., Kang, C. K., & Liu, H. (2013). An introduction to flapping wing aerodynamics (*Vol. 37*). Cambridge University Press.

G. Luo and M. Sun, The effects of corrugation and wing planform on the aerodynamic force production of sweeping model insect wings, *Acta Mech. Sin. 21, 531 – 541 (2005).*

T. Canchi, Numerical Simulation of Unsteady Aerodynamics in Insect Flight Using Generic Planform Shapes (University of New South Wales, Australian Defence Force Academy, School of Engineering & Information Technology, Australia,2012).

Wakeling J M and Ellington C P 1997 Dragonfly flight. II. Velocities, accelerations and kinematics of flapping flight *J. Exp. Biol. 200 557 – 82*

Wakeling J and Ellington C 1997 Dragonfly flight. I. Gliding flight and steady-state aerodynamic forces *J. Exp. Biol.200 543 – 56*

Azuma A, Azuma S, Watanabe I and Furuta T 1985 Flight mechanics of a dragonfly *J. Exp. Biol. 116* 79 – 107

Dickinson, M. H., Lehmann, F.-O. & G · · otz, K. G. 1993.The active control of wing rotation by drosophila. *J. Exp. Biol. 182, 173 – 189.*

Bergou A J, Xu S, Wang Z J. Passive wing pitch reversal in insect flight[J]. *Journal of Fluid Mechanics, 2007, 591: 321-337.*

Hefler, C., Noda, R., Shyy, W. and Qiu, H. (2017). Unsteady vortex interactions for performance enhancement of a free flying dragonfly. *ASME Paper. FEDSM2017-69579.*