Flow field induced by hovering insect

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Department of Physics, National Central University, 2016/05/29

Introduction

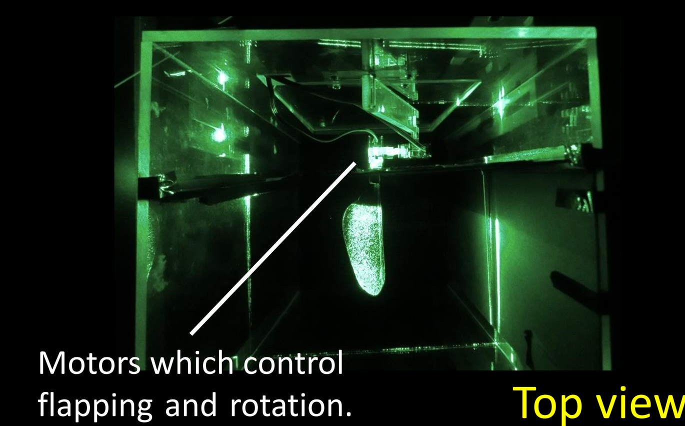
Insects can fly in the air through specific wing motions. Several vortices generated by wings are related to the motion of wings. In this work, we observe the flow field and study how these vortices are generated. The model of fruit fly is used in this experiment. It has common motions among insects.

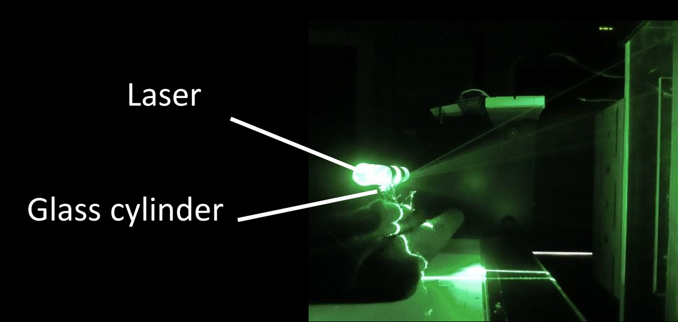
Basic concepts and analysis

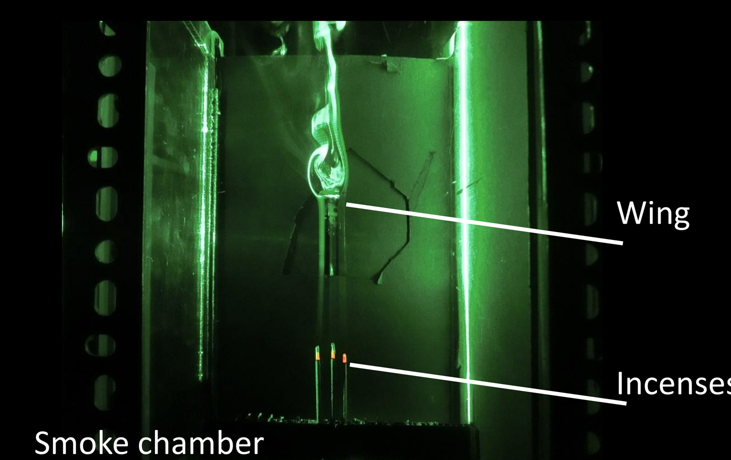
The air is incompressible when the velocity is small compared with the sound speed. The divergence of velocity is zero, which is the continuity equation. The flow is affected by inertia, pressure and viscosity. Reynold number is the ratio between inertia force and viscos force . It is about 200 for our insect. We record the motion and the corresponding field at different flapping phases. We want to find the relation between vortices and motions.

Setup

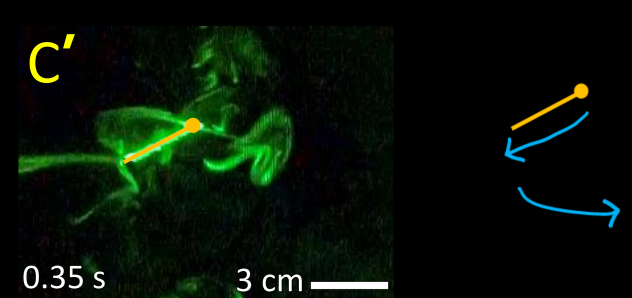
The mimic wing motion is achieved by two motors which control flapping and rotating. Incenses are put under the chamber so that the flow field can be tracked by smoke. Moreover, a laser sheet scattered by glass cylinder is useful to see two-dimensional field.





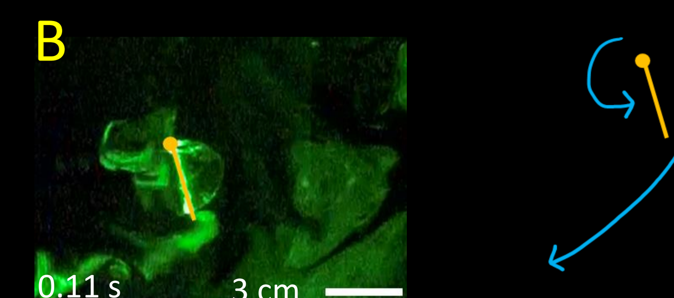


Vortex-wing interaction

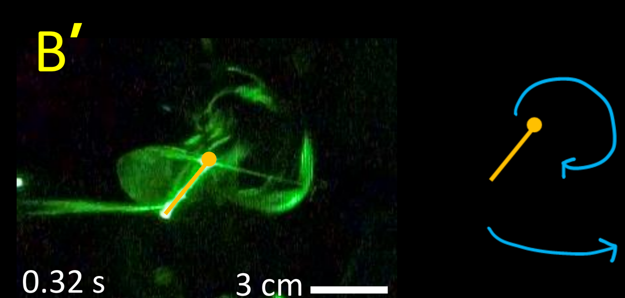


Similar to C.

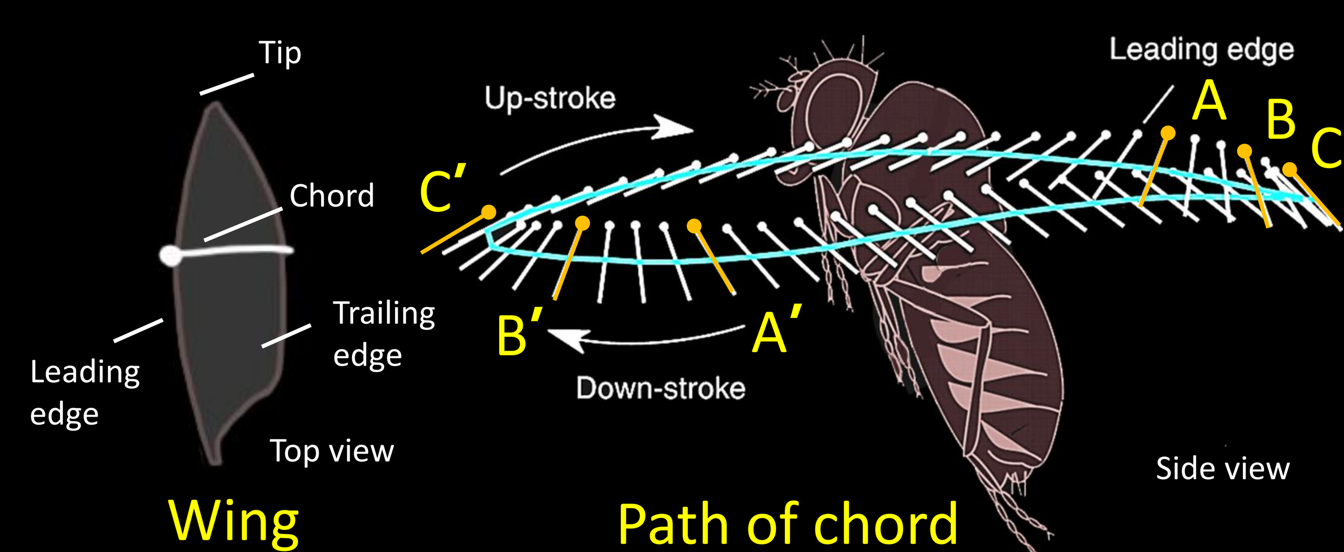
Translating wing from left to right.
→ Two vortices generated (←).



Slowing down and rotating wing
→ Flow follows the trailing edge vortex to go down.

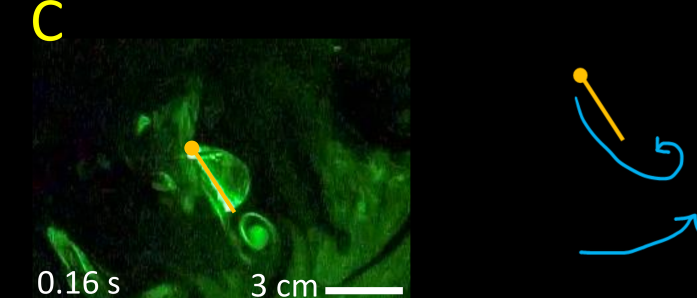


Similar to B.

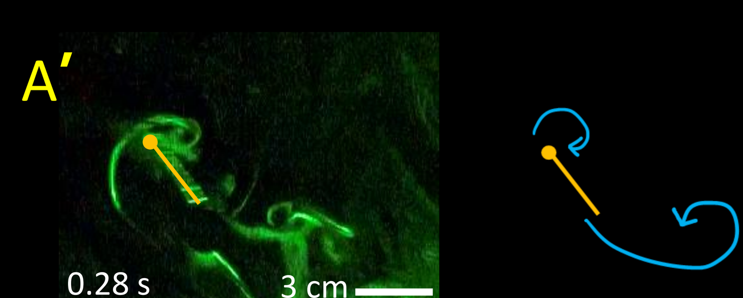


Wing

Path of chord



Rotating wing
→ Pulled flow from left to right.

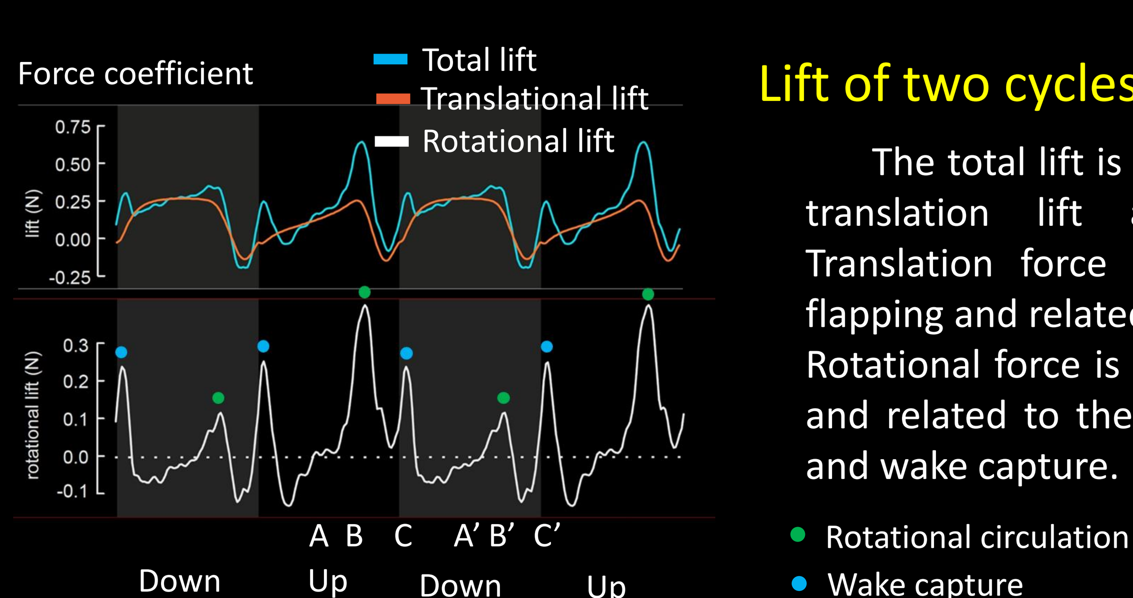


Similar to A.

Motion of wings

Chord is a section line of a wing. It can help us to indicate the position and angle of a wing. Stroke means a half cycle of the flapping motion.

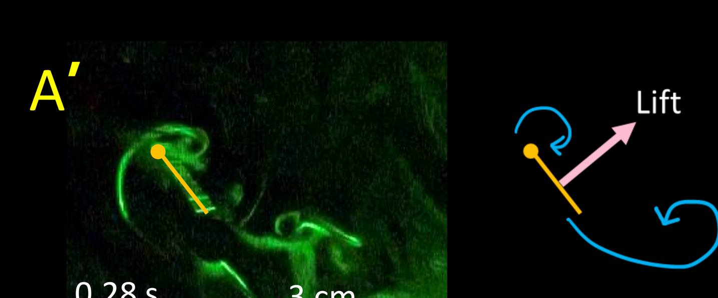
Lift-vortex relation



Lift of two cycles [2]

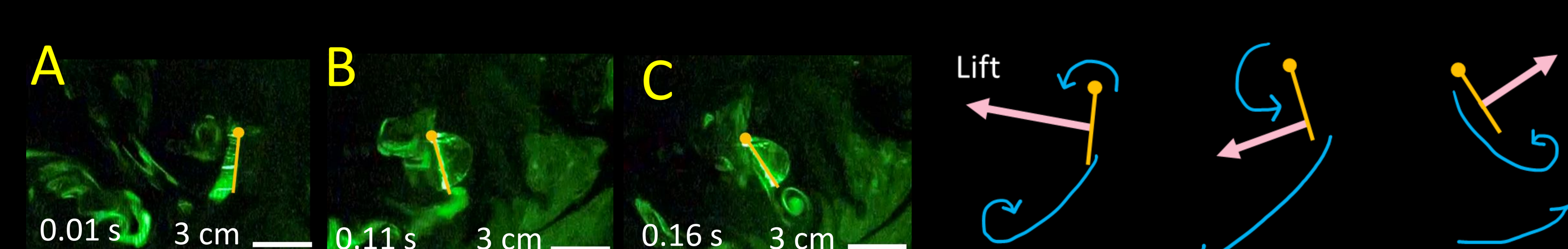
The total lift is the summation of the translation lift and rotational lift. Translation force is generated by the flapping and related to the wake capture. Rotational force is generated by rotation and related to the rotational circulation and wake capture.

Delayed stall



Delayed stall happens when a vortex stays at the leading edge of the wing. The flow on the wing is accelerated by the vortex. The wing is lift based on Bernoulli's law that flows with higher velocity get lower pressure, and vice versa.

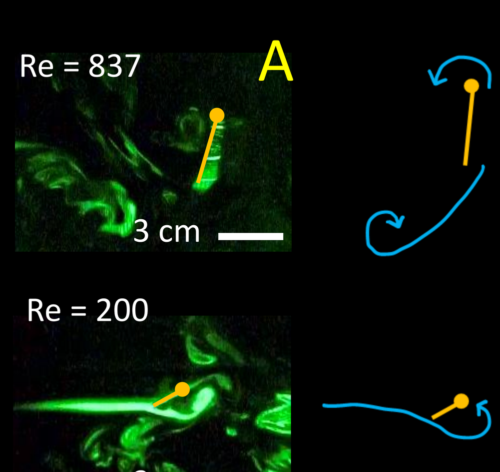
Rotational circulation and wake capture



Rotational circulation (happens at A and B) is related to viscous forces. The viscous force maintains the position of the trailing edge flow, so the wing pulls the flow during rotating. The pulling force generates a reverse force on the wing.

Wake capture (happens at C) is caused by the pulled flow. The pulled flow is an accelerated flow. It hits the static wing, so the lift is generated.

Reynold number, scale and incenses



Comparison

The smoke of incenses is used to be the tracker for the air flow. However, it has momentum which can destroy the vortex generated by the wing. We use less smoke in order to eliminate this effect.

The Reynold number of our experiment is higher than the flow near insects to eliminate the effect of incenses. However, similar mechanisms can be observed in our system.

$$Re = \frac{\rho v l}{\mu}$$

ρ: density. v: velocity. l: chord length.
μ: dynamic viscosity

Conclusion

- Using smoke and laser sheet, three mechanisms of lift enhancement for the insect flight are captured.
- The lift on an insect is dominated by the delayed stall, rotational circulation and wake capture.
- Delayed stall: vortex at the leading edge can create a low pressure region.
- Rotational circulation: reverse forces on the wing come from pulling the trailing edge flow.
- Wake capture: a lift force from the pulled flow hits on the wing as it stops.
- Reynold number doesn't affect too much on the flow field generated by the insect flight.

Reference

[1] Z. Jane Wang , David Russell. PRL 99, 148101(2007)
[2] Michal H. Dickinson, Fritz-Olaf Lehmann, Sanjay P. Sane. SCIENCE VOL 284 1999
[3] Sanjay P. Sane. J. EXP. Biol. 206, 4191-4208 2003