Enhancing thrust in robots that flap like insects

Details

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Funding

National Science Foundation and the Air Force Office of Scientific Research.

Bio

Dipan Deb is a postdoctoral research associate at Brown University, USA. Deb graduated from the University of California Irvine in December 2023 with a PhD in Mechanical and Aerospace Engineering.

Further reading

Deb, D, Huang, K, Verma, A, et al, (2023) Thrust enhancement and degradation mechanisms due to self-induced vibrations in bio-inspired flying robots. *Scientific Reports*, 13(1), 18317.

Balta, M, Deb, D, Taha, HE, (2021) Flow visualization and force measurement of the clapping effect in bio-inspired flying robots. *Bioinspiration & Biomimetics*, 16(6), 066020.

Enhancing thrust in robots that flap like insects

- Some flapping robots are designed to hover by flapping their wings like insects.
- The bodies of these robots vibrate as their wings flap, but so far, the influence of this vibration on their overall thrust has remained mostly unexplored.
- Dipan Deb, postdoctoral research associate, and his colleagues at the University of California, Irvine in the USA have explored the problem in a series of new experiments.
- They demonstrated that these self-induced vibrations can enhance thrust in more complex 4-wing mechanisms.

Insects are capable of hovering and that gives them a lot of advantages in nature. While some moth and bee species hover to feed on nectar without ever needing to land, hovering helps dragonflies to spot and catch their prey with pinpoint precision. Yet, regardless of the evolutionary advantage it brings, the mechanism used by all hovering insects is broadly the same. By flapping their wings about hundred times per second, they generate aerodynamic forces just strong enough to perfectly balance their weight.

In recent years, researchers and engineers have increasingly been inspired by these kinds of natural adaptations to develop new technologies. Through their research, Dipan Deb, postdoctoral research associate, and his colleagues at University of California, Irvine in the USA explore how the mechanisms employed by hovering insects could be replicated to design robots which can be utilised to study hovering flight.

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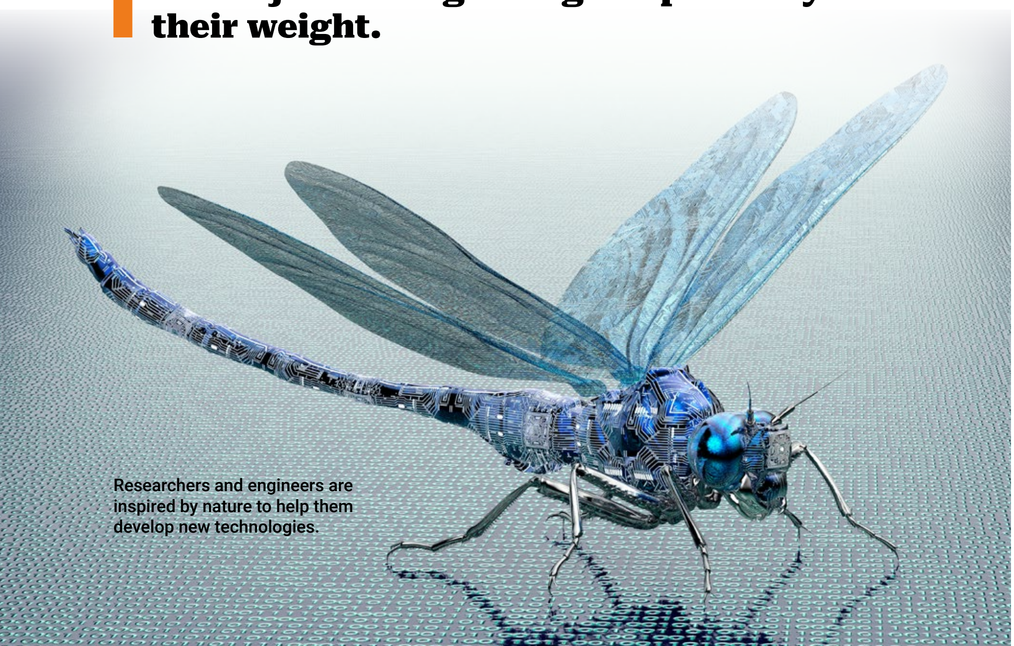


Researchers and engineers are inspired by nature to help them develop new technologies.

Self-induced vibrations

To study this flapping mechanism, the team considered its effects on the main bodies of bio-inspired flapping robots. One effect which may be less obvious when you watch an insect hovering is that its body will vibrate at the same frequency as it flaps its wings, since the vibration is enabled by flapping only. 'These vibrations are generated due to the wings flapping – the same mechanism that enables the insect to fly and hover,' Deb explains. These self-induced vibrations affect the generation of aerodynamic forces.

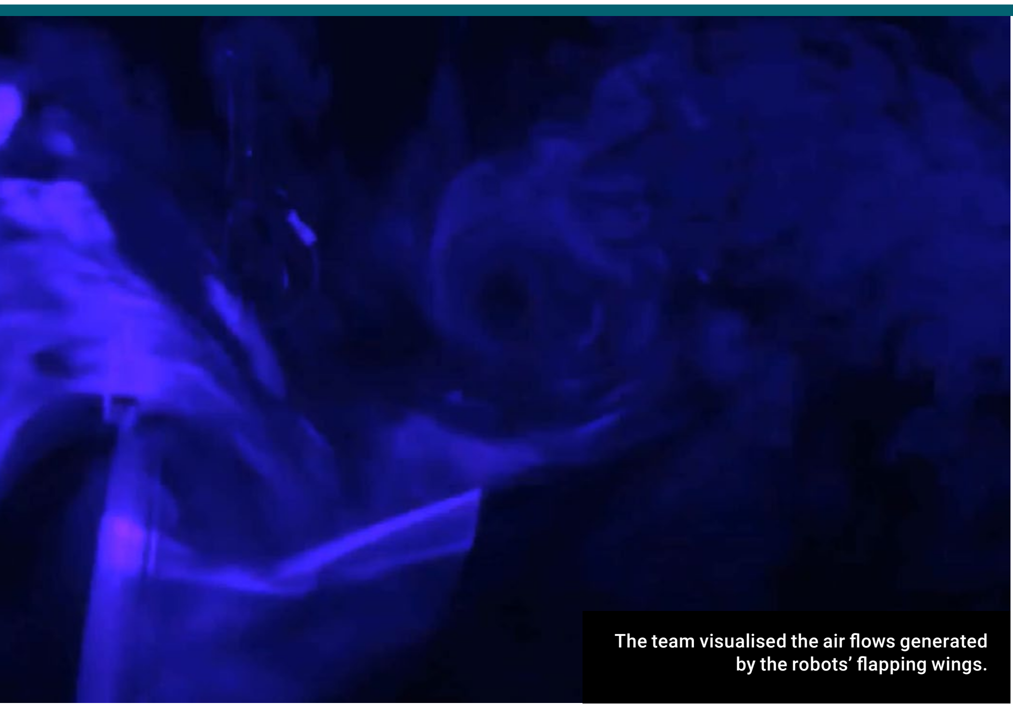
For Deb's team, the effect was particularly important to consider when testing the flapping mechanisms of flapping robots – since their experiments required them to measure the propelling forces as accurately as possible. To simplify these measurements, they constrained the number of directions the robots were allowed to move in.

Deb explains that an insect experiences these vibrations in six different directions: three translational and three rotational. For the team's study, however, they only considered the effect of these vibrations on the thrust, which is responsible for propelling the insect forward.

Loadcells and pendulums

With these constraints in place, the researchers used two different setups to measure thrust. Firstly, the team used a 'loadcell' setup which held the robot's body in place, suppressing any self-induced vibrations. As the robots flapped, the instrument converted their thrust into an electrical readout signal. The loadcell setup measured the robot's thrust at different points in time. Using this setup, Deb's team measured how thrust varies during the flapping cycle.

Secondly, the team measured thrust with a 'pendulum' setup, where they replaced the weight at the end of a swinging pendulum with a flapping robot – allowing



The team visualised the air flows generated by the robots' flapping wings.

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the robot's body to freely rotate. This time, the researchers measured the pendulum's angle of displacement from the bottom of its swing. By measuring this angle, the team then calculated the average thrust generated by the robot. This setup allowed vibration in the direction perpendicular to the pendulum rod, which is the same as the direction of the thrust. Therefore, this measurement included the effect of vibration in the direction of thrust.

Two different mechanisms

For each setup, the team tested robots with two different flapping mechanisms. The first was a simple 2-wing mechanism mimicking real insects; but the second was a more complex 4-wing mechanism, where two wings were arranged on top of each other on both sides of the robot. To generate thrust, each of these pairs moved in a clapping motion, which is known to enhance thrust. Deb describes that when the wings converge, they are in the 'clap' phase; and when they diverge, they're in the 'peel' phase. The whole motion is called the 'clap-and-peel' mechanism, or the 'clapping effect'.

Measuring thrust

In their experiments, Deb's team used a motion capture system to measure the flapping of the robots' wings, and the self-induced vibration of their bodies. For the loadcell setup, they could determine how the thrust generated by the robots varied over time by monitoring the strength of the electrical output signal. However, the pendulum setup required an alternative approach.

The team used mathematical modelling to predict and match the loadcell measurement with no vibration since they couldn't measure the time-varying thrust using the pendulum setup. Then, they applied the measured vibration in the mathematical model to predict the thrust variation with the vibration.

Visualising flow

The team carried out their experiments in a chamber filled with artificial fog, which allowed them to visualise the air flows generated by the robots' flapping wings. From their videos of the swirling fog, they could draw connections between the thrust imparted by the robots, and interactions between the air vortices generated by their wings. These flow patterns revealed key differences between the two types of flapping mechanism.

Mechanism-dependent thrust

Through their measurements, Deb's team discovered that the robots' thrust varied depending on whether they used the loadcell or pendulum setup. 'The 2-wing mechanism generated less thrust in the pendulum setup than the loadcell setup, but for the 4-wing clap-and-peel mechanism, the behaviour was the opposite,' Deb describes.

This showed that while the robots' self-induced vibrations diminished their thrust in the 2-wing mechanism, they actually enhanced it in the 4-wing mechanism. This discovery offers important insights into the aerodynamic forces generated by the insect-inspired robots, and could even inform designs for more efficient flapping robots in the future.

Personal response

Why does the clap-and-peel mechanism generate more thrust than the 2-wing mechanism?

The clap-and-peel mechanism in our study has four wings, two on each side. The phase during the flapping cycle, when the wings move away from each other, is called 'peel' motion. In this phase, when the wings peel away from each other, it creates a suction in between the wings. This suction draws air in from the ambiance. In the 'clap' phase when the wings move toward each other, the absorbed air gets pushed downstream and creates a 'jet' burst. This is analogous to a rocket. This jet is responsible for the enhanced thrust. This natural enhancement is absent in a traditional 2-wing mechanism.

What are the next steps for your research?

The clap-and-peel mechanism does not cease to surprise us. Apart from natural thrust enhancement and exploiting self-induced vibration, the mechanism has also been observed to have natural stabilisation. The clap-and-peel mechanism has been tested in a system of multiple degrees of freedom. At lower flapping frequencies, the response of the system has been observed to be unstable. However, beyond a certain flapping frequency, the system stabilises by itself. This phenomenon has only been observed in clap-and-peel mechanism. The next step in the research would be to explain the mechanism for the stabilisation.

What are some potential applications of insect-inspired flapping robots?

Since the clap-and-peel mechanism offers natural thrust enhancement and natural stabilisation, it is a very good choice for making a micro-air vehicle. We have developed such an air vehicle in our lab – the Quadflapper. We are using an assembly of four clap-and-peel mechanisms, which are controlled by a PID (Proportional – Integral – Derivative) controller. Using the PID controller, we are able to fly and control the Quadflapper. We have further noticed that it is easier to manoeuvre the Quadflapper than a conventional drone with similar dimensions and weight. Currently, we are on a quest to further improve the quality of the Quadflapper.