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AERIAL ROBOTS

Flapping wing drones show off their skills

Guido de Croon

The identification and solution of a major efficiency loss in small flapping wing drones lead to more agile aerobatic maneuvers.

Flying animals are capable of amazing feats, such as performing highly agile maneuvers to avoid a predator or covering enormous distances when migrating. In contrast to animals, which fly by flapping their wings, most flying robots (also termed "drones") rely on propellers for lift or propulsion. Presently, flapping wing drones are less mature as a technology than rotorcraft or fixed-wing drones (*1*). This is, in part, due to the difficulties of modeling the unsteady aerodynamics of flapping wings (*2*), precluding automated design optimization. Moreover, it is still unclear how to best design flapping wing drone hardware, such as the flapping mechanism, the wings, and the actuators.

Solving these challenges will be worthwhile because flapping wing drones promise numerous advantages: energy-efficient flight at small scales, a wide flight envelope (being able to hover and to fly fast forward, backward, and sideways), the ability to perform agile maneuvers, robustness against collisions, and easier acceptability due to their more natural appearance and sound (Fig. 1). Writing in this issue of *Science Robotics*, Chin *et al.* (*3*) introduce a new flapping mechanism design that achieves thrust generation with high energy efficiency. Consequently, it also enables their drone to perform more agile maneuvers.

Flapping wing drones are potential candidates for energy-efficient flight at small scales. In hovering mode, the thrust provided by the wings serves purely as lift for staying aloft. The thrust is generated by unsteady aerodynamic phenomena around the flapping wings, such as vortices occurring at the leading edge of the wing, which arise and vanish over the flapping cycle, and the inrush and outrush of air when wings peel apart or clap together, respectively (*2*). These phenomena result in high lift even at small scales, where the relative contribution of viscous forces grows in comparison to inertial effects. In contrast, fixed wings and rotating propellers will experience a deteriorating lift-to-drag ratio when scaling down. Hence, at small scales, flapping wings are expected to provide an advantage over the alternatives (*4*). The question remains whether we can realize that with our current technology. Revolving motors may be a better match for (extensively optimized) propellers. Moreover, scaling down not only negatively affects the efficiency of electric motors but also increases frictional forces when using a crank-rocker mechanism consisting of cogs and rods for converting the rotary motion of the motor to the translational motion required for the flapping stroke (*1*). This is exactly where Chin and colleagues provide additional insight. They identify shaft whirl (wobbling of the motor shaft) to be the root cause of most mechanical loss in a standard crank-rocker flapping mechanism. They solve this with an elastic mechanism consisting of nylon hinges and double shaft bearings, substantially improving energy efficiency. The researchers compare their flapping wing mechanism with various propellers directly mounted on the same motor. Their mechanism reaches a thrust-over-power ratio of ~6 gram-force/W compared to ~4.6 gram-force/W of the best propeller. Interestingly, they show that shaft whirl is a substantial problem for the propellers as well. Although this comparison will likely not be the final word on the comparison between flapping wing and rotary wing propulsion, the results are very encouraging.

The excess thrust of the researchers' design (40*g* for the 27.5-g drone) allows their flapping wing drone to perform agile maneuvers. It can first dart forward and then "air brake" by tilting the body up so that the wings and tail provide substantial drag. This makes the flapping wing drone come to a quick halt, while gaining height as kinematic energy is exchanged for potential energy. Subsequently, it can dive nose-down, brake, and perform a soft vertical landing. These agile maneuvers complete the authors' demonstration that flapping wings have a triple use for thrust, lift, and drag (for quick braking). Note that for braking, a quadrotor drone will have to tilt in the direction opposite to the motion to slow down, which reduces reaction time and efficiency.

The work of Chin and co-workers fits into the broader trend of flapping wing drones starting to live up to their promises, with centimeter-scale flapping wing drones able to fly untethered (*5*, *6*) and decimeter-scale flapping wing drones able to steer with their wings for enhanced agility (*7*, *8*). This is an exciting time for flapping wing drones because they are starting to provide insight into their natural counterparts (*8*) and they are also becoming mission capable (especially the larger drones). However, there are some daunting challenges on the way before flapping wing drones become a serious alternative to other drone types. One challenge is that most applications will require the flapping wing drones to fly completely by themselves, under extreme limitations in terms of sensors, computing power, and memory (*9*). Another challenge is to find the applications in which flapping wing drones can shine. Presently, companies use larger predator-like flapping wing drones for scaring birds away from airports (*10*) and smaller ones for toys or the entertainment industry, but the continuously improving capabilities are bound to break new ground and enable new applications.

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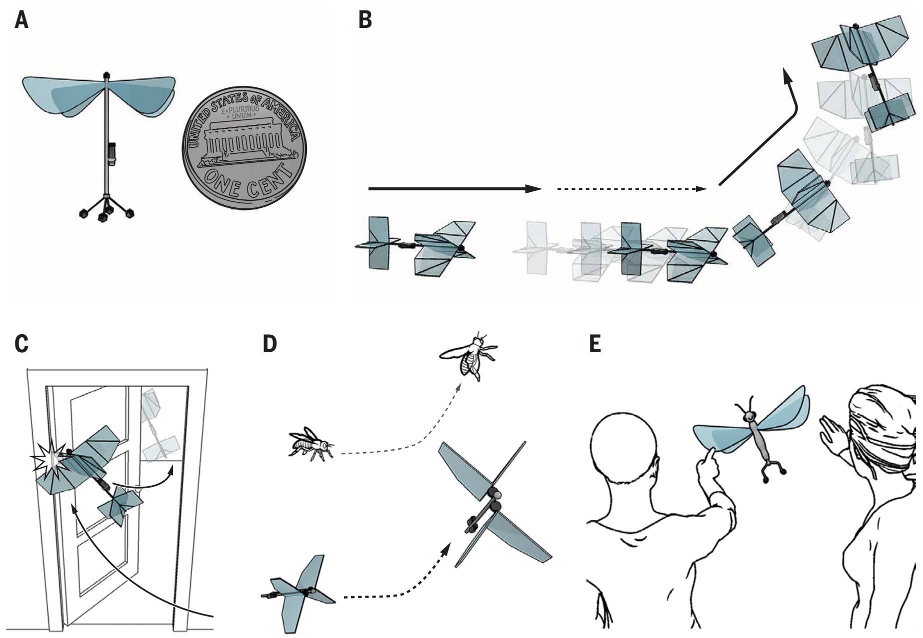

Fig. 1. Advantages of flapping wing drones. (**A**) Potential to scale down, thanks to the exploitation of unsteady aerodynamics. (**B**) Multiple flight modes with quick transitions between them: Flapping wing drones can fly fast forward, brake quickly with the help of the wings' drag, and then hover. Moreover, in the forward flight mode, the increased free stream increases the drone's lift and, hence, flight time. (**C**) The flexibility and the relatively low-speed flapping motion of the wings (0 m/s at the extreme, reversal point of the flapping cycle) allow flapping wing drones to cope well with collisions without need for additional structures. (**D**) The similarity of flapping wings with natural flyers facilitates the study of flying animals. In comparison with animals, flapping wing drones permit more repetitive tests, the logging of all sensory inputs, and full control of the behavior. (**E**) The lightweight, flexible wings and the relatively low speed make flapping wing drones safe for humans. Combined with the natural appearance and flapping wing sound, these features make flapping wing drones ideal for applications in indoor environments and close to humans, such as in search and rescue, greenhouse crop monitoring, or—as illustrated—in the entertainment industry.

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