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Inside JEB

FLYING FISH GLIDE AS WELL AS BIRDS

Hyungmin Park

We're all familiar with birds that are as comfortable diving as they are flying but only one family of fish has made the reverse journey. Flying fish can remain airborne for over 40 s, covering distances of up to 400 m at speeds of 70 km h^{-1}. Haecheon Choi, a mechanical engineer from Seoul National University, Korea, became fascinated by flying fish when reading a science book to his children. Realising that flying fish really do fly, he and his colleague, Hyungmin Park, decided to find out how these unexpected aeronauts stay aloft (p. 3269).

But getting hold of flying fish to test in a wind tunnel turned out to be easier said than done. After travelling to Japan to try to buy fish from the world famous Tsukiji fish market, the duo eventually struck up a collaboration with the National Federation of Fisheries Cooperatives of Korea. Park went fishing in the East Korean Sea, successfully landing 40 darkedged-wing flying fish. Selecting five similarly sized fish, Park took them to the Korean Research Centre of Maritime Animals, where they were dried and stuffed, some with their fins extended (as in flight) and one with its fins held back against the body, ready to test their aerodynamics in the wind tunnel. Fitting 6-axis force sensors to the fish's wings and tilting the fish's body at angles ranging from –15 deg to 45 deg, Park and Choi measured the forces on the flying fish's fins as they simulated flights.

Calculating the flying fish's lift-to-drag ratios – a measure of the horizontal distance travelled relative to the descent in height during a glide – Choi and Park found that the flying fish performed remarkably well: gliding better than insects and as well as birds such as petrels and wood ducks. And when they analysed how the fish's lift-to-drag ratio changed as they varied the tilt angle, the duo found that the ratio was highest and the fish glided furthest when they were parallel to the surface, which is exactly what they do above the ocean. Measuring the airborne fish's pitching moment, the duo also found that the fish were very stable as they glided. However, when they analysed the stability of the fish with its fins swept back in the swimming position it was unstable, which is exactly what you need for aquatic manoeuvrability. So flying fish are superbly adapted for life in both environments.

Knowing flying fish always fly near the surface of the sea, Choi and Park then decided to find out if the fish derived any benefit from the aerodynamic effect of flying close to the surface. Lowering the fish's height in the wind tunnel they found that the lift-to-drag ratio increased as the fish models 'glided' near the floor. And when Park replaced the solid surface with a tank of water, the lift to drag ratio rose even more, allowing the fish to glide even further. So, gliding near the surface of the sea helps the fish to go further.

Finally, Choi and Park directly visualised the air currents passing around the flying fish's wings and body. Blowing streams of smoke over the fish, the duo saw jets of air accelerating back along the fish's body. Park explains that the tandem arrangement of the large pectoral fin at the front and smaller pelvic fin at the back of the fish's body accelerates the air flow towards the tail like a jet, increasing the fish's lift-to-drag ratio further and improving its flying performance even more.

Having shown that flying fish are exceptional fliers, Choi and Park are keen to build an aeroplane that exploits ground effect aerodynamics inspired by flying fish technology.

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Park, H. and Choi, H. (2010). Aerodynamic characteristics of flying fish in gliding flight. *J. Exp. Biol.* **213**, 3269-3279.

BEES CAN BALANCE THEIR DIET

Something is going wrong with our bees. Across North America and Europe, large numbers of bees are routinely wiped out by colony collapse disorder, putting many agricultural crops at risk. 'There is no single cause of colony collapse. It looks like it may be a mixture of pests and diseases; a decline in bee habitats and pesticides may be involved too. There will also be a nutritional component,' says Sue Nicolson from the University of Pretoria, South Africa. Knowing that bees have to regulate their pollen and nectar consumption from a variety of sources to remain healthy on a balanced diet, Nicolson and her colleagues, Solomon Altaye, Christian Pirk and Robin Crewe, decided to find out whether young nurse bees can maintain a balanced diet when offered a

choice between imbalanced diets made from different protein sources (p. 3311).

Designing the diets that the bees would dine on, Nicolson selected three protein sources: casein, a pure protein derived from milk; royal jelly, produced by bees as a food source for larvae and the queen; and Feed-Bee®, a commercially available bee food supplement derived from plant sources. Calculating the protein and carbohydrate content of the royal jelly and Feed-Bee® supplement, Nicolson and her colleagues added sucrose to each protein source to produce four diets with protein-to-carbohydrate ratios of 1:50, 1:25, 1:10 and 1:1. Then the team collected groups of 100 newly emerged adults from local African bee populations – which seem to be immune from colony collapse – isolated each group in a cage in a warm (35°C) incubator (to simulate hive conditions), and provided them with water and a choice of diets. Some of the caged groups were offered the choice between 1:50 and 1:10 diets, while others were given 1:50 and 1:1 diets. Other colonies had access to 1:25 and 1:10 diets, while the last group were offered 1:25 and 1:1 diets.

Monitoring the bees' consumption and mortality rates over 14 days, Nicolson and her colleagues could see that each colony adjusted how much it consumed from each food source to ensure that it got a balanced diet. While the colonies provided with casein-based diets balanced their intake so that they consumed 1 mg of protein for every 12 mg of sucrose, the colonies on royal jelly diets consumed slightly more carbohydrate (14 mg) to every milligram of royal jelly protein, and the Feed-Bee® protein bees consumed the least amount of carbohydrate, at only 11 mg of carbohydrate per milligram of Feed-Bee® protein. The team also noticed that the bees on casein-based diets had lower mortality rates than bees fed on the other protein sources, and the bees fed on royal jelly had the highest ovary activation rates, suggesting that a bee's diet can dramatically affect its life history, and that high dietary protein levels may not be as essential as many beekeepers think.

Nicolson admits that she was surprised that the bees required so much carbohydrate in their diet, and suspects that the workers have much higher metabolic rates than other social insects as they all contribute to regulating the environment in the colony. She is also keen to find out how adding larvae to the equation could alter the bees' diets. According to Nicolson, young adults produce royal jelly, which has a 1:1 protein-to-carbohydrate ratio to feed young, and this could shift the bees' nutritional requirements, forcing them to increase their protein consumption to meet the larvae's needs. Ultimately Nicolson hopes that this information will help us to understand one of the many causes of colony collapse and reverse its devastating effects.

10.1242/jeb.050872

Altaye, S. Z., Pirk, C. W. W., Crewe, R. M. and Nicolson, S. W. (2010). Convergence of carbohydrate-biased intake targets in caged worker honeybees fed different protein sources. *J. Exp. Biol.* **213**, 3311-3318.

DUELLING BATS TRAIL EACH OTHER

When a single bat targets a tasty treat, it closes in quickly for the kill. But what happens when a competitor tries to muscle in on the act? What strategies do competing bats use to catch their prey in aerial dogfights? Knowing how individuals pursue stationary and moving prey, Chen Chiu and her colleagues from the University of Maryland wondered how duelling bats track each other and their prey as they compete to catch a snack (p. 3348).

Chen Chiu first became interested in this problem when she was training bats to catch tethered mealworms. 'Sometimes I used to let two or three bats fly together and compete for the worm. I found they chased each other and one dominant bat got the worm,' remembers Chiu. Intrigued by the behaviour, Chiu and her colleagues, Wei Xian and Cynthia Moss, decided to record the bats' manoeuvres and echolocation calls to find out how competing bats hunt.

Releasing pairs of bats into a 7 m×6 m×2.5 m flight enclosure, the trio filmed the duelling animals in infrared light while recording the bats' echolocation cries with 16 microphones as they competed for a suspended mealworm. Remembering that individual bats catch the tethered mealworms within a matter of seconds, Chiu says, 'In the two bat situation, they were circling around the room for a while and did some chasing. It usually took about one minute for one of the bats to get the prey.' Chiu also noticed that over the course of the dogfight, the trailing bat usually outmanoeuvred the leader in the closing moments to catch the reward.

Next, Chiu analysed the direction of each bat's echolocation calls to find out where the trailing bat was 'looking' as it pursued the leader. 'This was pretty difficult,' laughs Chiu. Having successfully allocated each echolocation call to one of the two bats, Chiu teamed up with P. S. Krishnaprasad and Puduru Reddy to compare the direction that the trailing bat was flying with the direction of the invisible line that joins the two bats' positions at all times to find out how it tracked its rival. If the trailing bat was simply following the leader, the direction that it was flying would always point towards the leader, but if the trailing bat was using the strategy that individual bats use when hunting free-flying prey, then the trailing bat would fly so that the invisible line (joining it to the leading bat) maintained a constant orientation as the bats progressed.

Surprisingly, the pursuing bat was simply following the leading bat instead of using the strategy that individual hunters use when tracking prey. The team also noticed that when the bats flew head on towards each other they averted their cries, presumably to avoid jamming each other's echolocation signals.

So why is the trailing bat more successful at catching prey than the leading bat? Chiu suspects that the trailing bat is at an advantage because it might be able to disguise its presence by going quiet during the pursuit, as well as chasing the leading bat off in the final crucial moments before trapping the prey. The team also suspects that when large groups of bats leave their roosts 'en masse', they may use the same pursuit strategy, following the bat in front to successfully avoid collisions with their neighbours.

10.1242/jeb.050864

Chiu, C., Reddy, P. V., Xian, W., Krishnaprasad, P. S. and Moss, C. F. (2010). Effects of competitive prey capture on flight behavior and sonar beam pattern in paired big brown bats, *Eptesicus fuscus*. *J. Exp. Biol.* **213**, 3348-3356.