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Winging It: Flying Fish Aerodynamics Directly Measured for the First Time

Wind tunnel tests find that flying fish glide as well as some birds

By Ferris Jabr Friday, September 10, 2010 3

A fish out of water is not usually a graceful or impressive sight, unless that fish is flying—or hovering inside a laboratory wind tunnel.

The members of the flying fish family soar above the waves on unusually large pectoral and pelvic fins, which act as wings. Although scientists have studied the anatomy and behavior of these peculiar finned gliders, understanding flying fish aerodynamics has never been more than educated guesswork: Researchers have approximated the physics based on known aerodynamics of other gliding animals with similarly shaped wings. Now, for the first time, a pair of researchers has directly measured the way that air flows around flying fish fins inside a wind tunnel, used the data to confirm earlier assumptions about how fish fly, and concluded that these fish glide as well as some birds. The new study, by mechanical engineers Hyungmin Park and Haecheon Choi of Seoul National University in South Korea, appears in the September issue of *The Journal of Experimental Biology*.

"Before, there wasn't any real experimental data about lift and drag," said Frank Fish, a West Chester University of Pennsylvania zoologist who has studied flying fish but was not involved in the recent study. "This is a step forward in that they actually have taken the bodies of the animals and put them in wind tunnels."

The National Federation of Fisheries Cooperatives in Seoul provided Choi and Park with 40 darkedged-wing flying fish (*Cypselurus hiraii*) freshly caught in the Sea of Japan (East Sea). After freezing the fish in an icebox the researchers selected five fish that were the most similar in size and asked the Korea Research Center of Maritime Animals to dry and stuff the fish bodies, using urethane foam to maintain appropriate anatomical geometries. The researchers extended the pectoral and pelvic fins of three stuffed fish so they resembled biplanes, they extended only the pectoral fins of a fourth fish, and retracted all the fins of the fifth specimen, giving it the shape of a torpedo. Then the researchers gave each fish a turn inside a wind tunnel and compared how air moved around the differently arranged fins. The experimenters also attached force sensors to the fish and varied the angles of their bodies inside the tunnel, to assess which angles created the greatest lift or drag.

In further tests the researchers installed a tank of water beneath the tunnel to investigate how gliding just above the surface changes the way air moves around fins. To see these effects more clearly, the experimenters also observed how smoke flowed around the fins.

The analyses yielded a few key findings. First, Choi and Park confirmed that the angles that achieved the greatest lift in the wind tunnel were the same steep angles at which flying fish emerge from the water in the wild. Second, the researchers found that when the fish glided exactly parallel to the water—as observed in nature—they maximized their lift–to–drag ratio, ensuring they stayed airborne for as long as possible. Third, Choi and Park observed that the biplane arrangement of pectoral and pelvic fins helped stabilize the fish in flight, preventing them from pitching up or down. Fourth, they ascertained that flying fish glided just as effectively as some birds, such as hawks, petrels and wood ducks—all of which are excellent gliders. Finally, they discovered that flying fish achieved incredibly efficient flight when gliding just above the water's surface—reducing drag up to 14 percent—because of something called ground effect.

Normally, a flying fish gliding some distance above the water experiences drag because of a difference in air pressure over the fin surface. The air pressure is higher below the fin than above and "that high pressure below wants to move toward the low pressure on top," Fish explains, "but that can't happen except at the wing tip, where the airflow starts to move around the tip and up to the top of [the] wing. Because you are moving forward, a wingtip vortex forms—a swirling mass that creates a long cyclone trailing behind the animal on each fin or wing tip." These vortices are a major source of induced drag, but when a fish nears the water's surface the vortices start to break up. At the same time, pressure builds below the fins, increasing lift. The combined effect makes gliding just above the water's surface more energetically efficient than free flight. The ground effect is also responsible for the slight jolt you may feel when an airplane is moments away from touching down on the runway.

Flying fish can stay airborne for distances up to 400 meters by coupling the ground effect with a behavior known as taxiing, in which they whip their tail through the water while still aloft to reaccelerate whenever they are in danger of sinking below the waves. Some flying fish have even evolved specialized tail fins with enlarged lower lobes, providing greater thrust during taxiing to help keep them airborne. Two major hypotheses offer explanations for why flying fish fly: one hypothesis says that fish fly to escape ocean predators; the other argues that fish save energy when gliding instead of swimming.

Although Fish acknowledges the inherent flaws in drawing conclusions about behavior in nature based on laboratory tests with stuffed animals, he thinks the new study is the most accurate measurement of flying fish aerodynamics to date. "The problem that you always have with a stuffed system or a model is how close to reality it actually is: we don't know the exact geometry of the wing when it's deployed, for example," Fish says. "But does this get you into the ballpark? It's a closer approximation than what was done previously. It's probably pretty close to reality." Choi emphasizes how careful he was to preserve the living anatomy of the fish, especially the delicate fins.

Both Fish and Choi agree that the new research could have applications for airplane design. "Maybe the flying fish design is very good for traveling over the water surface and economizing fuel consumption," Fish says. "It's conceivable we could have little messengers going out over the ocean." Choi refers to improving the design of wing-in-ground-effect (WIG) vehicles, which are specifically constructed to take advantage of the ground effect. "One of our next lines of research," Choi says, "is to apply what we learn from flying fish to these special planes."

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Name/Period/Date

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1. How do flying fish fly?
2. Where has this new study been done?
3. Describe the experiment setup.
4. Explain air flow issues involved with flying fish.
5. Explain how lift and drag affect flying fish.
6. How far can flying fish stay airborne?
7. Explain a flaw in the experiment.