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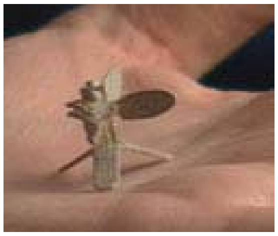
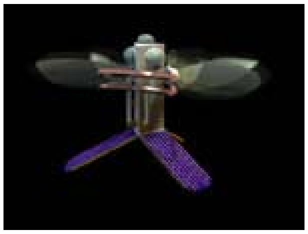
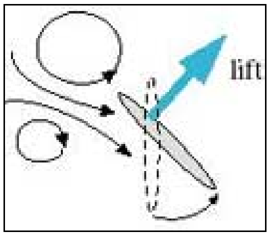
HOW DO FLIES FLY?

Not like birds and airplanes, says Michael Dickinson, 37, professor of integrative biology at the University of California at Berkeley. Birds and airplanes stay airborne on wings whose shape and angle create lower pressure above the wing, which helps lift them. Their flight is explained by a theory called "steady state aerodynamics." But flies' wings are constantly flapping—nearly 200 times a second—and the wings move mostly side to side, not up and down.

To understand the aerodynamic forces generated by flies, Dickinson built a huge model of the wings of a fruit fly, *Drosophila melanogaster*. Dubbed "**Robofly**," the contraption mimics the atmospheric effects of a fruit fly's one-millimeter-long wings flapping in air. Dickinson and his team built a 25-centimeter (15-inch) robotic wing, which flaps and rotates at one-hundredth a fly's speed in a two-ton tank of mineral oil. Three motors move the robotic wing back and forth in precise motions determined by a computer. Bubbles pumped into the tank show the aerodynamic patterns. Sensors measure the forces on the wings during each phase of the stroke.



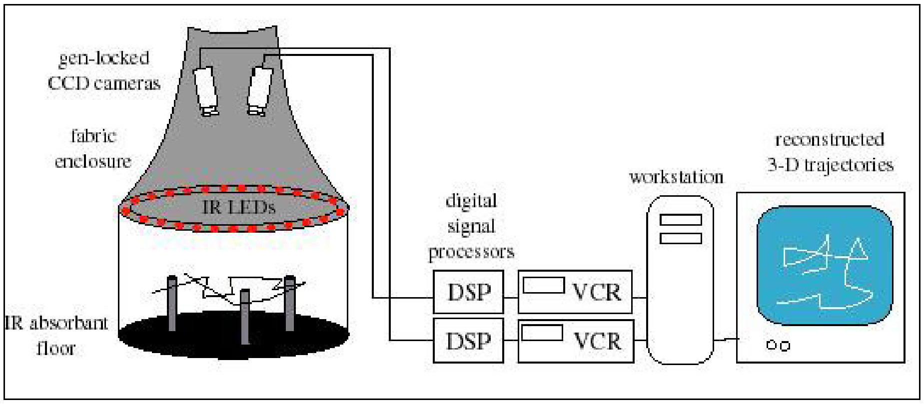




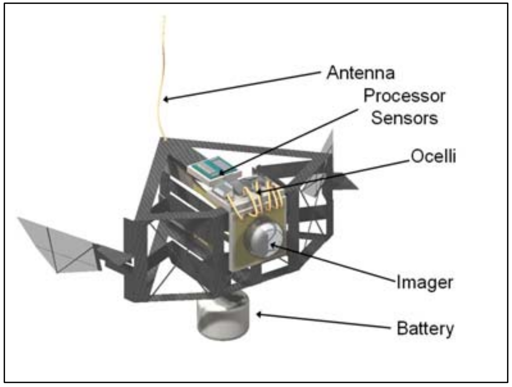
Experiments with "Robofly" showed that insects use three different aerodynamic mechanisms to stay in the air. They first confirmed a previous theory, devised by a number of labs over the last 20 years, that a phenomenon called "delayed stall" occurs in the middle of the stroke. When the insect sweeps its wings forward, a whirlpool or vortex of air is created on top of the wings. This vortex seems to create a low-pressure zone that produces lift.

The team also discovered that two previously unknown forces occur at the end of each half-stroke. When the wing rotates backward to change direction, air is pulled over the top faster than the bottom, a force called "backspin." Like a tennis ball with backspin, the wing is pulled upward by lower pressure. In perhaps the biggest surprise, another type of lift—"wake capture"—is also created when a wing starts to change direction. The wing actually passes through a spinning vortex wake from the previous stroke. Dickinson says the wing can extract enough energy from this previous stroke to create significant upward lift.

To understand flies' flight mechanics and behavior, Dickinson and his team observe free-flying fruit flies in the "Fly-o-Rama." Researchers place flies in an enclosed chamber (picture below) and use cameras to track the flies' flight paths in three dimensions. As they travel through space searching for food, the flies seem to make a series of amazing 90-degree turns. Dickinson is now trying to determine how much of their turning is guided by vision, and how much is determined by their gyroscopes. For more information on this project, click here.

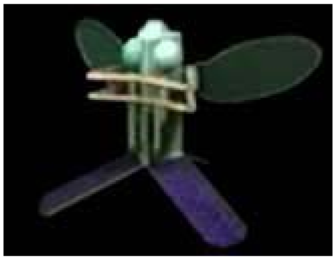


Micromechanical flying insect (MFI) project

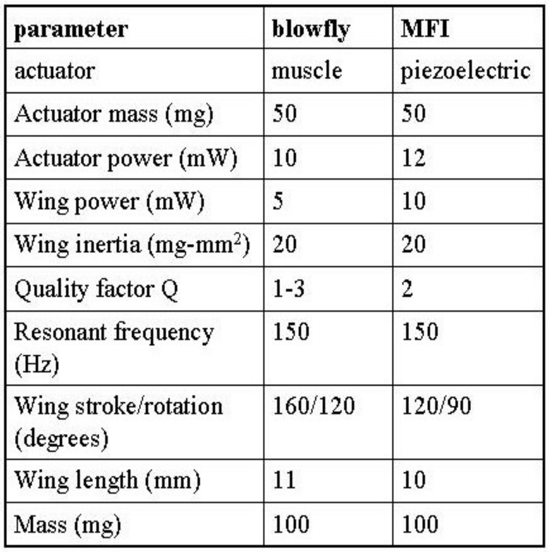


UC Berkeley engineers, working with the Center for Information Technology Research in the Interest of Society (CITRIS), have created a tiny wing that flaps and generates lift. Their goal: a flying robot weighing less than a paper clip—one that could be used in monitoring and reconnaissance.

The goal of the micromechanical flying insect (MFI) project at UC Berkeley is to develop a 25-millimeter (wingtip-to-wingtip) device capable of sustained autonomous flight. The MFI design is based on biomimetic principles to capture some of the exceptional flight performance achieved by true flies. The high performance of true flies is based on large forces generated by non-steady state aerodynamics, a high power-to-weight ratio motor system, and a high-speed control system with tightly integrated visual and inertial sensors. Design analysis shows that piezoelectric actuators and flexible thorax structures can provide the needed power density and wing stroke, and that adequate power can be supplied by lithium batteries charged by solar cells.



As a design target, the MFI group is using the blowfly *Calliphora.* The animation (left) shows a micromechanical flying insect taking off and landing. The animated robot rests on a tripod of solar panels and has polyester wings and stainless steel struts. The wings aren't able to do the complex arcs that a fly can manage, but they can do simple things, like flap and rotate. In this simulation, the wings are about half an inch long and look like miniature paddles. To see a mechanical version click here.



parameter	blowfly	MFI
actuator	muscle	piezoelectric
Actuator mass (mg)	50	50
Actuator power (mW)	10	12
Wing power (mW)	5	10
Wing inertia (mg-mm^2)	20	20
Quality factor Q	1-3	2
Resonant frequency (Hz)	150	150
Wing stroke/rotation (degrees)	160/120	120/90
Wing length (mm)	11	10
Mass (mg)	100	100

A set of the most relevant parameters is shown in the table (left). The first critical determination was whether enough mechanical power could be delivered to drive the wings.

The actuator mass for the MFI model is comparable to the blowfly as single-crystal piezoelectric actuators potentially have greater power density than muscle at high wing beat frequencies. The model needs to have comparable wing inertia and damping to keep Q low and manage high controllability.

Initial tests have produced thrust forces on a flight mill. The next step will be to design a suitable power generation unit, flight control unit, and communication unit for remote control.

The plan is to concentrate on stable hovering, with simple optical sensing and a rudimentary onboard gyroscope. The eventual goal is to fabricate an autonomous MFI. For more, click here.

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