New aircraft capable of fast, accurate and repeatable flight

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How does a bird handle the wind, hanging effortlessly while battered by gusts and darting through clusters of trees with seamless precision? Department of Electrical Engineering and Computer Science Associate Professor Russ Tedrake wants to understand how birds can operate under such conditions and create machines that can do the same. His current goal is to develop an aircraft that can fly like a bird, darting through trees and narrowly avoiding obstacles during fast-paced flight.

Tedrake and the Robot Locomotion Group, his research group at the Computer Science and Artificial Intelligence Laboratory (CSAIL), recently unveiled a video of a new computer-controlled aircraft that is able to accurately perform knife-edge turns, rolling 90 degrees to dart through an opening narrower than the aircraft’s wingspan.

This research is part of a five-year multi-research initiative funded by the Office of Naval Research, led by Tedrake and involving researchers from Carnegie Mellon University, Harvard, MIT, New York University and Stanford University, to develop a bird-sized unmanned aerial vehicle (UAV) capable of fast, accurate and repeatable flight at speeds of 10-15 meters per second. The aircraft developed by Tedrake and his team can currently operate at speeds of up to 7-8 meters per second.

“We are inspired by birds, but we are not trying to build a system that is exactly mimicking them,” says Andrew Barry, a graduate student in Tedrake’s research group. “We are trying to take ideas from nature and then build an engineered system.”

To create a UAV capable of flying like birds, Tedrake’s research group first designed a special aircraft that could handle high-speed flight. With the help of Professor Mark Drela, of MIT’s Department of Aeronautics and Astronautics, the group built an aircraft outfitted with fiberglass-plated foam wings that remove the need for ailerons, flight control surfaces typically used for roll control on aircraft, and instead actuate the entire wing, allowing for maximum maneuverability. The center of the plane is made of rubber so that the plane can withstand collisions. The vehicle has a wingspan of 28 inches and with all of the onboard instrumentation, including high-speed stereo cameras, it currently weighs in at 573 grams (1.26 pounds).

“The plane is like a three-dimensional, high-tech, jigsaw puzzle that contains almost no glue. It consists of over 30 independent pieces, many of which slide or snap together," says Tim Jenks, a senior in mechanical engineering who is working in Tedrake’s research group. "Many of these pieces are laser-cut designs that could easily be produced in large quantities."

At present, the plane is operated using a motion-capture system similar to those used in Hollywood, but in the future researchers are planning to implement a vision system for guiding and controlling the aircraft.

Controlling an aircraft that is performing such dexterous movements at high speeds is difficult due to the complexity and unpredictability of airflow at high angles of attack, such as when performing a knife-edge turn. Before flight, computer models allow the researchers to plan a trajectory through the obstacles. Then, thanks to a time-varying linear quadratic control system, the plane can be accurately guided through knife-edge maneuvers. During flight, a remote computer computes the trajectory of the aircraft and sends the results wirelessly to the plane, where onboard computers send electrical signals to the motors, which activate the aircraft’s wings.

The team decided to test its work with a knife-edge demonstration because the maneuver forced them to solve a tricky control problem.

“We picked the knife-edge experiment because it forces us to solve all the right problems,” Barry says. “It’s a challenge and control problem, as the aircraft has to be able to fly accurately and really quickly. Also, it’s tricky to get the aircraft to roll accurately because the air flow isn’t necessarily smooth.”

“The challenge for the knife-edge task was to generate trajectories for the plane that pushed the hardware to the boundary of what it is capable of while still being able to follow the trajectory consistently and safely,” says Anirudha Majumdar, a graduate student in Tedrake’s group. “I see the task in the video as a small step toward the broader task that we've set ourselves of flying through cluttered environments like forests. The approach would be to have a large ‘library’ of trajectories similar to the one in the video that the plane can choose from as its sensors provide more information about the trees/obstacles in front of it.”

Ultimately, the goal of Tedrake’s work is to gain a better understanding for control theory, and how to operate machines under complex and varying conditions such as aerodynamic disturbances. Working on a project like developing an aircraft that can fly like a bird and perform knife-edge turns allows Tedrake and his team to test the effectiveness of their control systems with pretty clear results.

“[This project] forces us to ask the right question for the right reasons,” Tedrake says. “Having hardware like this keeps us honest in evaluating our work to better understand control theory.”