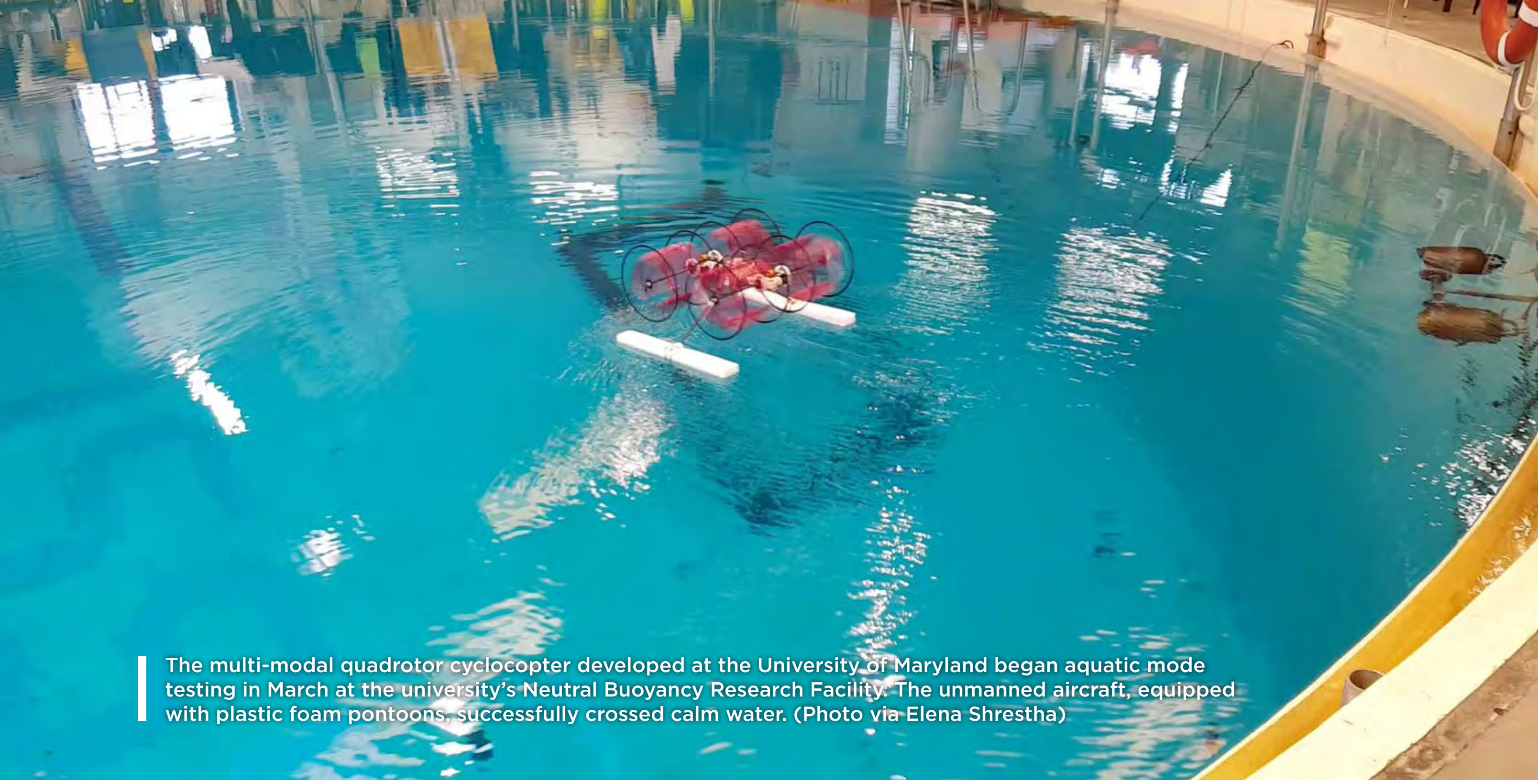

The multi-modal quadrotor cyclocopter developed at the University of Maryland began aquatic mode testing in March at the university's Neutral Buoyancy Research Facility. The unmanned aircraft, equipped with plastic foam pontoons, successfully crossed calm water. (Photo via Elena Shrestha)

Paddlewheel Propulsion Is Now Vertical and Multi-Modal

Cyclocopter technology could make mini VTOL drone flight more stable and agile, as well as traverse ground or water.

By John M. Doyle

The US Army's quest for autonomous reconnaissance aircraft that could fit in the palm of a soldier's hand has led to a breakthrough in vertical lift technology by researchers utilizing a concept long-known but never successfully demonstrated: the cyclocopter.

With funding from the Army Research Laboratory (ARL), engineers at the University of Maryland and Texas A&M University (TAMU) have been designing, building and flying tiny cyclocopters … but at least one researcher thinks it might be possible someday to scale the technology up to accommodate human flight.

A cyclocopter is a vertical lift aircraft with a ring of rotor blades that extend horizontally like the wings of an airplane and rotate around a horizontal axis, moving in a cycloidal way, like a paddlewheel on a riverboat. In flight, the cycloidal rotors in their circular housing look something like a spinning hamster wheel (sans hamster). The angle of the rotor blades can be varied, altering lift and thrust, and allowing the aircraft to shift seamlessly from vertical to horizontal flight. The rotating multiple, uniform blades provide the aircraft with 360 degrees of thrust vectoring.

The cyclorotor concept is more than 100 years old, with recorded experiments dating back to 1909. Early researchers focused on manned flight and were never able to demonstrate a vehicle that could fly, despite several attempts in the 1930s.

Army Funding

Anticipating challenging battle environments that military forces will face in future conflicts, the ARL's Micro Autonomous Systems and Technology (MAST) program began looking for promising technologies that would provide portable air and ground situational awareness devices for soldiers moving on foot through complex terrain, like dense urban areas. MAST's Collaborative Technology Alliance (MAST-CTA) was created in 2008 to encourage cooperation among the military, industry and 20 research universities. Maryland's aerospace engineering department was tapped as the program's Center on Microsystem Mechanics, one of four centers for technology concentrations like electronics or autonomy.

"We didn't start out saying we wanted to do a cyclocopter design," said Brett Piekarski, collaborative alliance manager at MAST-CTA. Army officials were interested in developing autonomous micro air vehicles (MAVs). Existing small unmanned aerial vehicles (UAVs) had trouble maintaining stability in wind gusts. The Army also was looking for a UAV that was agile enough to deal with complicated and crowded environments like urban areas, but there were few that were robust, agile, maneuverable, autonomous and small enough. The problem was finding systems that were able to deal with environmental constraints "and the cyclocopter was one innovative approach," said Piekarski, adding: "The [cyclocopter] concept has been around for a long time, but nobody had successfully demonstrated the capability in sustained controlled flight — which Maryland, of course, has done through a lot of developmental understanding of the program."

At Maryland's Alfred Gessow Rotorcraft Center, student researchers have built small unmanned cyclocopters ranging in weight from just over 2 oz (60 g) to 2.2 lbs (1 kg). The largest of the little drones is multi-modal — designed to travel across air, land and water.

At Texas A&M's Advanced Vertical Flight Laboratory, researchers have also developed a range of increasingly smaller cyclorotor-powered drones, including one that weighs 29 g (just over 1 oz) — currently the smallest ever made.

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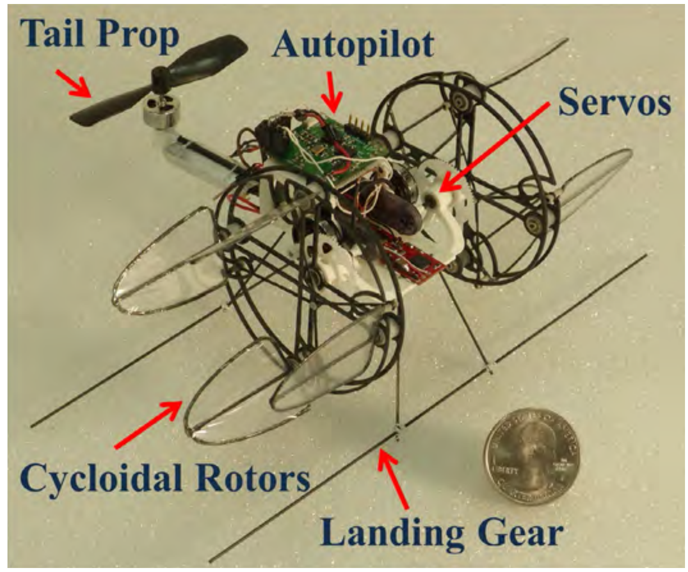
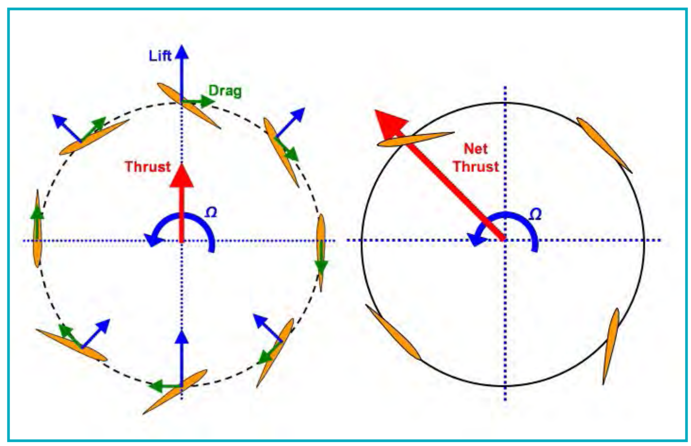
University of Maryland

Led by Prof. Inderjit Chopra, director of the Gessow Rotorcraft Center, students and post-graduate researchers have achieved many firsts in cyclocopter design, including the first ever stable flight of a cyclocopter MAV in 2011. The cyclocopter, equipped with two side-by-side one-inch (2.5-cm) diameter rotors, plus a small nose rotor for control and stability, demonstrated forward flight purely through thrust vectoring, rather than pitching the vehicle forward as helicopters do. The Maryland development team included research scientists Dr. Moble Benedict, Dr. Vikram Hrishikeshavan, and Dr. Derrick Yeo, graduate research assistant Elena Shrestha, and undergraduate research assistants Brian Davis and Benjamin Williams. Benedict left Maryland in 2014 for Texas A&M, where he continues his cyclocopter work.

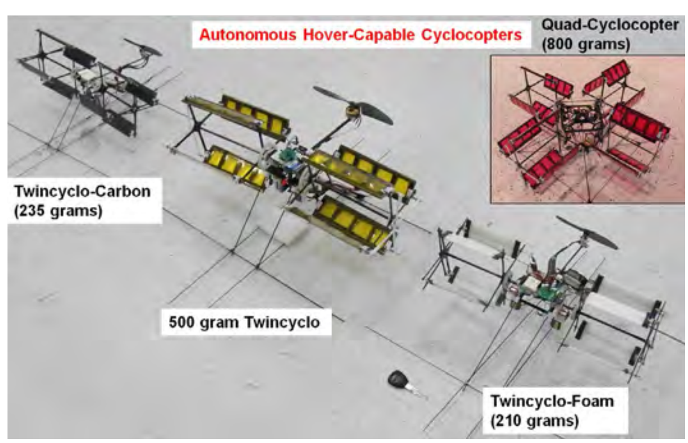
The latest development at Maryland is an MAV-scale quad-cyclocopter that moves through the air or on land. The red rotor blades, which resemble the paddle wheel of a Mississippi riverboat, are made of carbon fiber struts overlaid with polystyrene foam and a Mylar sheathing. "Most of the components for this vehicle were manufactured in this lab," Shrestha said, including a postage stamp-sized, 1.3-g (0.05 oz) autopilot designed by Hrishikeshavan, which allows autonomous flight for very small UAVs and contains tri-axial gyros, a processor and wireless communications. The multi-modal cyclocopter has simple carbon fiber landing skids that lower just before landing and fold up after takeoff. Overall, the fragile looking aircraft has six servos, four for flight and two to power the landing gear. For terrestrial movement, the landing skids rise and the round outer frames housing the rotors double as wheels. The vehicle has been clocked at 4.5 mph (2 m/s) on the ground. Stopping or slowing rotors on one side while moving forward on the ground allows the drone to turn and corner like a fast moving army tank.



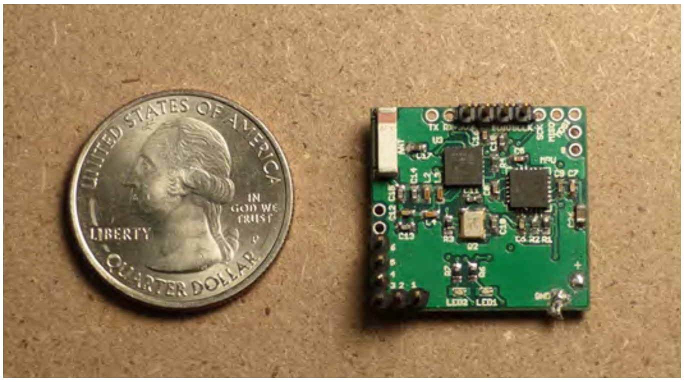
Under the leadership of Dr. Benedict, the TAMU Advanced Vertical Flight Lab has been progressively shrinking cyclocopters in size, until his group achieved the world's smallest cyclocopter, weighing just 29 g (1 oz). (Photo via Moble Benedict)



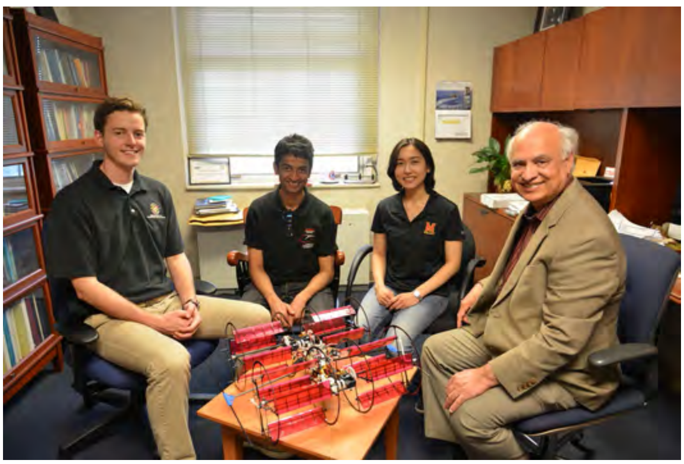
The individual rotor blades change angle cyclically. Varying the individual blade angles changes the thrust vector from hover (left) to any direction (right), providing the aircraft with 360 degrees of thrust vectoring. (Graphic via Carl Runco)



When at University of Maryland, Moble Benedict developed four different sizes of cyclocopters. (Photo via Moble Benedict)



A postage stamp-sized, 1.3-gram autopilot, designed at Maryland by Vikram Hrishikeshavan, allows autonomous flight for very small UAVs. The tiny board compresses tri-axial gyros, a processor, wireless communications and other sensors into one lightweight device. (Photo via Carl Runco)



Left to right: Maryland's Brian Davis, Dr. Vikram Hrishikeshavan, Elena Shrestha and Dr. Chopra with the multi-modal quadrotor cyclocopter. Not pictured are Dr. Derrick Yeo and Benjamin Williams who are also involved with UMD's cyclocopter research. (Photo by Jennifer Figgins Rooks)

In March, the quad-cyclocopter began testing its aquatic mode, "driving" across the surface of a water tank with polystyrene pontoons attached to the landing skids. "We want to get a transition from all three modes," said Shrestha, adding that she and colleagues are working on enabling the cyclocopter to take off while on water. Adding the pontoons and water-proofing the copter's electrical components adds 3.9 oz (110 g) to its weight. After using a higher capacity LiPo (lithium-ion polymer) battery, the team has flown the quad-cyclocopter with the pontoons and is working to demonstrate transition. Hovering mode is also the least energy efficient, she said. Movement on water uses 92% less power than hover mode, while land locomotion uses 88% less.

Texas A&M University

Moble Benedict received his PhD at Maryland with a dissertation on cyclocopters. Under his leadership, the TAMU Advanced Vertical Flight Lab has been progressively shrinking cyclocopters in size, until he and graduate students Carl Runco and David Coleman achieved the world's smallest cyclocopter, weighing in at just 29 g. As Benedict notes, each rotor assembly had to weigh just 2.5 g (0.09 oz) — the equivalent of five breath mints.

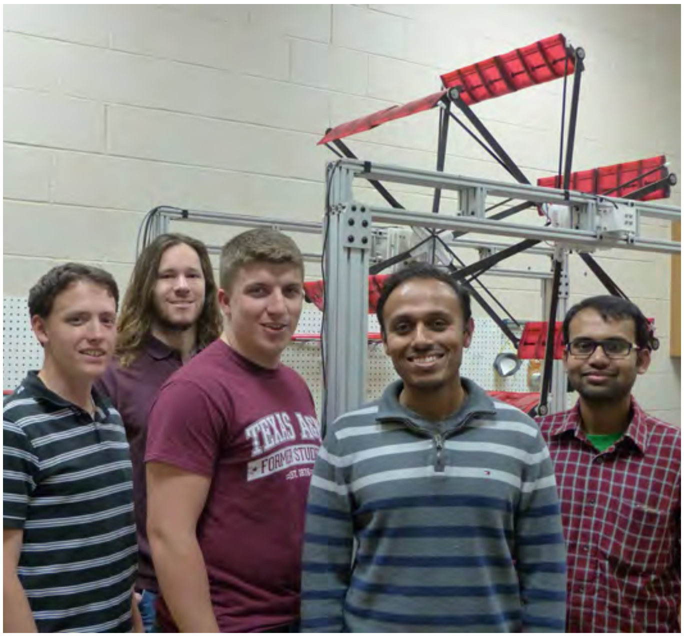
"It's absolutely viable. It definitely has advantages when you're talking about great turbulence,"

The idea is to switch between different modes to conserve power and ultimately improve range and endurance performance of the quad-cyclocopter.

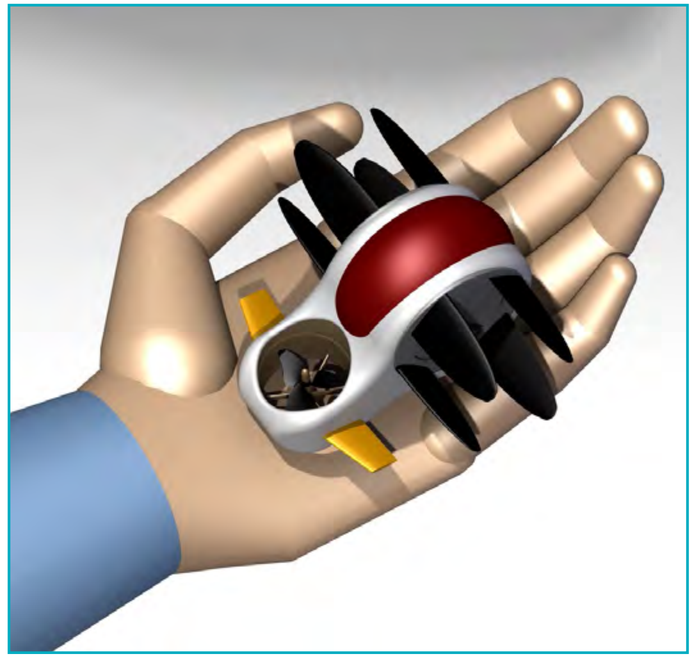
Unlike most cyclocopter models, this one has rotor blades shaped like the end of a canoe paddle where it meets the water. Runco explained that in shrinking the size of the cyclocopter, weight had to be reduced and one solution was to stiffen the rotor blades so less carbon fiber rod was needed and the end plate supporting the outer ends of the rotors was eliminated. "The elliptical shape had a lot to do with that," he said, adding, "It also works out to be a very aerodynamically efficient shape."

Hrishikeshavan's autopilot, developed at Maryland, was also crucial, said Benedict. "I don't think Moble's 29 gram cyclocopter would be 29 grams if it did not have that," said Christopher Kroninger, the MAST-CTA program mechanics area lead.

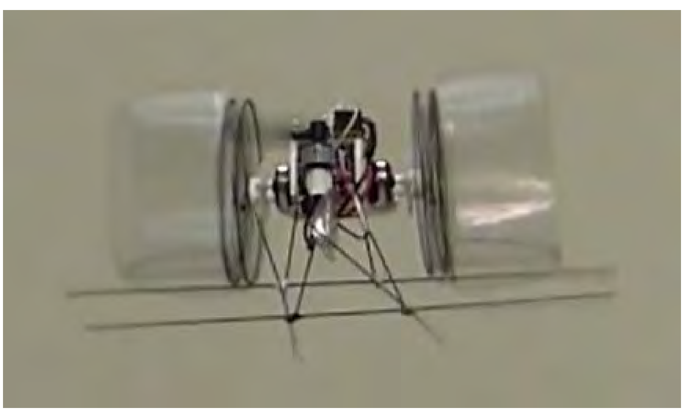
The multi-modal quadrotor cyclocopter can fly in the air and travel across the ground using its cyclorotor endplates as wheels. It is shown here with the foam pontoons for aquatic operations — the skids are raised for terrestrial locomotion. (Image via Elena Shrestha)



The Texas A&M cyclocopter team in front of its test rig for a 10 lb (4.5 kg) twin-rotor cyclocopter. Left-to-right: David Coleman, Carl Runco, Adam Kellen, Moble Benedict and Atanu Halder; not shown: Carolyn Walther. (TAMU photo)



Conceptual drawing of a future meso-scale cyclocopter. (TAMU graphic)



The Texas A&M 29 g cyclocopter in flight. (Frame capture from a TAMU video)

The Future

Is there an actual application for cyclocopters?

"It's absolutely viable. It definitely has advantages when you're talking about great turbulence," said ARL's Kroninger. The MAST program, which will end Sept. 30, focused on basic research and will not make acquisition recommendations in reporting its findings, Piekarski said, but "we developed a lot of new understanding, a lot of new theories. They've been able to demonstrate they can fly them and control them."

Hrishkeshavan thinks disaster and rescue operations in places too hazardous or difficult for terrestrial travel would be a likely early use of cyclocopters. Shrestha believes their cyclocopter's ability to avoid detection by going from the air to the ground would make it useful in covert surveillance and reconnaissance. There are also "many, many non-military applications [for a cyclocopter] if you could scale it out to a few kilograms," said Benedict. "It doesn't require a runway. It can fly vertically," he added. Cyclocopters can transition from vertical to horizontal flight more efficiently than helicopters or tilt-rotor aircraft simply by adjusting the phasing of their rotor blades, and they could be "inherently much quieter," he said.

He thinks cyclocopters might theoretically be scaled up to accommodate a human operator, although he acknowledges the large rotor blades necessary to provide the lift could present safety hazards for use as a private air service or personal copter. However, Benedict thinks cyclorotors could be used to power airships. "That's where you can really use thrust vector to push-pull the aircraft up and down. With cyclorotors, "you don't need 30 people to tether an airship to the ground." He noted that in the 1920s, the US Navy considered mounting Kirsten-Boeing cyclorotors on a dirigible, the USS *Shenandoah*, but the semi-rigid airship crashed in a storm before the switch could be made.

After a dozen years working on cyclocopters, "I strongly believe this is indeed a promising concept," said Benedict. "It's a new way to fly. If you look at any of the UAVs or MAVs today, they're still aircraft using conventional rotors in a different concentration. They are all using the same fundamental propulsive system. But cyclorotors are completely new in that sense. We have to try these new, out-of-the-box concepts."

About the Author

John M. Doyle spent 27 years as a writer and editor with the *Associated Press* and *Aviation Week & Space Technology*. As a freelance defense and aviation journalist he writes frequently about the manned and unmanned vertical lift aircraft needs of the military, homeland security and private sector. His website is **http://4GWAR.wordpress.com** and can be reached at ***jmdoyle52@gmail.com***.