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Flying Eyes for Foot Soldiers – DARPA's Micro Air Vehicle

By Frank Colucci

The Micro Air Vehicle demonstrator takes off and lands vertically. Untethered flight tests required an FAA Certificate of Authorization for tests on the Laguna Indian Reservation in New Mexico. (Honeywell)

Launched and controlled by dismounted soldiers, backpack-portable Micro Air Vehicles (MAVs) that hover and stare at the enemy have already downlinked real-time imagery to US Army platoon leaders. Last September and October, an Advanced Concept Technology Demonstration (ACTD) managed by the Defense Advanced Research Projects Agency (DARPA) gave soldiers ducted-fan MAVs developed by Honeywell Defense & Space. The military utility assessment recommended changes in the Transitional MAV (T-MAV) system and started developing tactics, techniques, and procedures for a refined man-portable UAV in the Army's Future Combat Systems.

The ACTD gave troops of the 2nd Battalion, 5th Infantry Regiment, 3rd Brigade, 25th Infantry Division at Schofield Barracks, Hawaii five 40-pound T-MAV systems, each including a ground station, two gasoline-powered air vehicles, and support equipment. "The ACTD route is an interesting route," according to Honeywell unmanned aerial system program manager Vaughn Fulton. "There's nothing like putting your system in the hands of the user." Over three-and-a-half weeks, the users ran 60 urban assault, route reconnaissance, and convoy security exercises with and without the MAVs.

The soldiers graded the experience mostly favorable in after-action reports. "They liked the ability to look forward and down," says program manager Dr. Brad Tousley in the DARPA Tactical Technology Office. "It gave them situational awareness of the Opposing Forces." OPFOR snipers in the laser-scored exercise area were driven from their usual firing points by the flying eyes. According to Dr. Tousley, "They were picked out immediately by the MAVs on the rooftops, so they quickly abandoned the high ground."

Starting this October, another round of experiments with the 25th ID will give a Stryker vehicle brigade 25 T-MAV systems with 50 air vehicles for a year-long evaluation. The 25th ID may take some of those gasoline-powered T-MAVs to a combat theater in 2007. Favorable decisions after the second user test could begin an Army-led System Development and Demonstration (SDD) phase for a diesel-fueled D-MAV. Alternatively, the Micro Air Vehicle may merge with the Army's Small UAV program to replace the hand-launched, fixed-wing Raven.

Straight Up

The networked Future Combat Systems (FCS) attains Initial Operational Capability around 2014 with four classes of Unmanned Aerial Vehicles (UAVs) to serve platoons, companies, battalions, and larger formations. DARPA is investigating the ducted fan configuration for the Class I Micro Air Vehicle and the Class II Organic Air Vehicle in platoons and companies. Though fixed-wing UAVs promise greater range and endurance, ducted fans can hover and stare at targets of interest, and they offer special advantages in man-portable systems.

Vertical Takeoff and Landing (VTOL) makes ducted fan MAVs inherently easier than fixed-wing UAVs to launch and recover in confined mountain, jungle, or urban settings. The contained fan is protected from impact with trees and buildings and makes the vehicle quicker to deploy and safer to handle. The ducted fan also lends itself to a smaller package readily carried by dismounted soldiers. The current T-MAV is about 13 in. in diameter and weighs 15.5 lb dry or 17 lb with full fuel. A complete system with ground station fits in two regular Army MOLLE (MOdular Lightweight Load-carrying Equipment) packs.

DARPA's Micro Air Vehicle program started in 2001 and focused on technology required for control, power and propulsion, and navigation and communications. The agency concluded in the autumn of 2003 that a hybrid-electric fixed-wing MAV was beyond current technology. However, a ducted fan MAV ACTD was funded by DARPA, the US Army, and the Office of the Secretary of Defense to put the small VTOL UAVs into the hands of users, fast.

To speed development, the ACTD started with a Transitional MAV powered by a modified gasoline engine with about 4 hp. The two-stroke engine made by 3W in Germany is commonly used in radio controlled competition aircraft. Volatile gasoline poses an obvious hazard in a man-portable battlefield system, but a safer, more efficient 3 to 4 hp diesel or heavy-fuel engine compatible with the Army One Fuel initiative remains in development.

With its objective engine, the ducted fan D-MAV is supposed to fly at up to 40 kt and hover for 60 minutes at sea level, 40 minutes at 5,500 ft, or 20 minutes at 10,000 ft. Those requirements emerged from the Army's FCS Class I Operational Requirements Document (ORD) and the draft Small UAV ORD, with input from the 25th Infantry Division, the Training and Doctrine Command, the Dismounted Battle Lab, and the Aviation and Missile Command.

Aviate, Navigate, Communicate

The ducted fan generates thrust by accelerating air through its core. It creates lift on the airfoil lip of its circular duct in vertical hover and inclined forward flight. The generally symmetrical duct wall contributes some extra lift as the vehicle tilts and gains speed in inclined flight. Moving flaps at the base of the duct direct the fan thrust to stabilize and steer the vehicle. The current T-MAV has flap actuators commonly used in high-end radio controlled aircraft.

Tests at the Military Operations Urban Terrain sites at Fort Benning and Schofield Barracks gave Army users the chance to fly the MAV in built-up areas. (US Army)

Thrust is generated within the duct by a fixed-pitch, direct-drive fan. "Variable pitch/speed mechanisms add complexity and weight," explains Mr. Fulton. "Both are deal-killers in this size range." Engine speed also gives the ducted fan a very straightforward altitude control loop. The engine and fan speed up for the vehicle to climb and slow down to descend. Hover is achieved at equilibrium around 7,000 rpm. Fan speed varies automatically with density altitude.

Allied Aerospace did preliminary wind tunnel studies with the ducted fan configuration for DARPA and in May 2003 flew an untethered 29 in. diameter UAV representative of an FCS Class II vehicle. However, a smaller, Class I version was a more difficult proposition. The aerodynamic stator that straightens the fan stream and the moving flaps that steer the thrust posed design challenges. "In this size frame, you only have only so much room for control surfaces." says Mr. Fulton. "In the small, MAV-sized air vehicle, you're constrained in the area in which you can work."

Also challenging, the unstable shape required fast, complex control inputs. DARPA chose Honeywell to implement the necessary control functions in the company's Micro-ElectroMechanical Systems (MEMS). MEMS technology was itself the product of a DARPA ACTD and put into production for the Joint Direct Attack Munition (JDAM). It uses semiconductor manufacturing techniques to integrate commercial microprocessors with gyroscopes, a magnetometer, and air data sensors in an Inertial Measurement Unit/Flight Management Unit (IMU/FMU). The IMU/FMU stabilizes and controls the MAV for autonomous flight.

Rather than fly the MAV with a joystick, users program the Honeywell-designed ground station with flight plans including surveillance hover time. The vehicle flies itself to the target and sends imagery to the ground station up to 10 km away. The IMU/FMU also manages sensors and communications and contains a GPS navigation receiver. Honeywell figures say the package senses horizontal position with 10 m accuracy and pressure altitude within 4 m.

Honeywell Labs in Minneapolis provided insight into MAV control laws, and the company's Ridgeway, Minnesota unit integrated the control logic into a MEMS package. A six-way competition led Honeywell to choose UAV-maker AAI to fabricate the ACTD air vehicles. AVID LLC did performance modeling for the air vehicle, engine, and fan design, and Honeywell Engines and Systems in Phoenix helped design the fan duct, supported by aerodynamic flow studies done by Sandia Labs. Wind tunnel tests were run at Virginia Tech with assistance from Techsburg. DARPA engineers worked closely with the MAV team throughout the design and development.

The ducted fan MAV has a 13 in. diameter shroud. Quick-change E/O and IR pods each contain forward looking and downward looking camera. (Honeywell)

Make It Fly

At 5,800 ft above sea level, the Honeywell facility in Albuquerque, New Mexico provided sufficient density-altitude for MAV tethered testing. The vehicle was tied between two 90 ft poles about 400 ft apart. Tethered tests enhanced safety with an unproven vehicle and enabled Honeywell engineers to explore instabilities without risking test assets in a crash. Before the first free flight, the small ducted fan flew about 400 times on a tether in a parking lot to validate the flight control system. Mr. Fulton recalls, "We started with the very inner loops of our flight controls on-tether and moved outward, expanding the vehicle envelope."

Untethered envelope expansion nevertheless required more space. Honeywell worked with the FAA to get a Certificate of Authorization for MAV tests on the Laguna Indian Reservation about 45 miles from Albuquerque. "The Laguna facility was nice in that it gave you the space to fly 10 km and back," says Mr. Fulton. Also significant, the Laguna site at 7,500 ft above sea level provided hot day density altitudes greater than 10,500 ft for government acceptance testing.

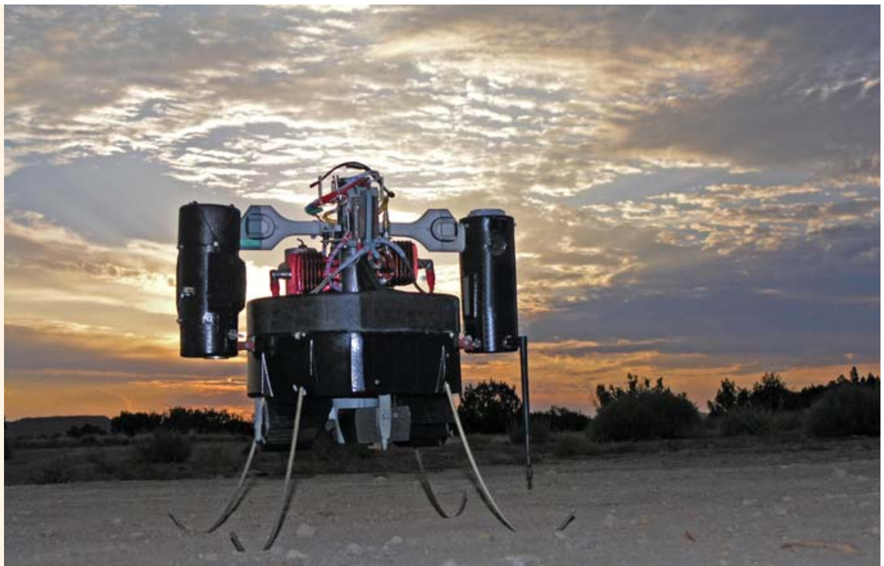
The T-MAV made its first untethered flight in March 2005. The autonomous two-minute sortie included take-off, flight to a waypoint, and landing. Subsequent flights followed a traditional test program with about 100 performance points. The MAV test program included about 150 free flights at Laguna. In late spring and early summer 2005, two DARPA observers verified MAV navigation precision and endurance, and a 10,500 ft operating altitude. Dr. Tousley notes, "Rotors have difficulty at altitude. To fly something this small that high was a big achievement."

MAV development testing used the MEMs IMU/FMU to provide primary flight control and to collect flight test data. Mr. Fulton says, "We looked at putting a separate telemetry system and sensors on the vehicle as they do with larger vehicles. Size, power, and weight just precluded that." The 1 lb payload of the T-MAV is fully occupied by quick-change camera pods.

The two-way UHF control link provided enough spare bandwidth to carry test telemetry. Typical flight tests telemetered over 250 parameters at 1 to 25 Hz. An extended telemetry set provides another 200 parameters at up to 600 Hz. A wireless modem was added to carry more data, "We use that primarily in the debug mode and to validate some of the fast control loops," explains Mr. Fulton. The current vehicle also has a 1.7 GHz downlink for streaming video and can store 10 minutes of imagery on-board or 60 minutes of surveillance on the ground station.

Honeywell engineers filmed all flights but used no radar or other ground instrumentation to track the MAV. "The composite material used to build this vehicle means it is not picked up by radar well," says Mr. Fulton. "Analysis showed we'd have to hang a bunch of extra material on the vehicle to use radar systems, so we didn't do that." However, a commercial falconry transponder made by Marshall Radio Telemetry was attached to the free-flying vehicles in case one got lost.

Government acceptance testing included an operational and functional MAV test in which a user hiked several hundred meters with a system backpack, deployed a vehicle, and sent the air vehicle on three missions in one day.



The gasoline-powered T-MAV weighs 15.5 lb dry or 17 lb fully fueled. It carries a payload around 1 lb that left no margin for dedicated test instrumentation.

To The Users

Five complete T-MAV systems went through a second round of acceptance testing in the instrumented Fort Benning Military Operations Urban Terrain (MOUT) training area. In about 100 flights, soldiers again verified speed, range, control and video links, and other functional requirements by day and night, in clear weather and rain. "They actually flew it below treetop level through the streets of their own MOUT site," says Mr. Fulton.

Individual soldier experiments at Fort Benning in July and August 2005 cleared the way for the unit-size ACTD sponsored by the US Pacific Command. The T-MAV systems used at Fort Benning were reconditioned by Honeywell for the 25th ID in Hawaii. "Their goal was really to start developing the tactics, techniques, and procedures one would use to employ the system," says Mr. Fulton. About 40 soldiers were trained on the T-MAV system. Senior non-commissioned officers got about 40 hours of instruction to "train the trainers." Enlisted users got about 16 hours of training.

The Schofield Barracks training area provided an opportunity for a field user to develop MAV unit tactics, techniques, and procedures. "The platoon leader decided how to employ the vehicle. We could not tell him in advance," explains Dr. Tousley. The infantry officer developed brevity codes for efficient communications, and set up MAV launch and landing points 300 to 400 meters from his rally point to keep the noise of the demonstrator vehicles from cuing the Opposing Forces to his unit movements.

DARPA goals include a 70 dB noise level at 100 m for the T-MAV and 60 dB for the D-MAV. "We significantly beat that goal," says Mr. Fulton. Honeywell is addressing both engine and aerodynamic noise to make a quieter air vehicle.

Mr. Fulton cautions, "You really have to work both of them in concert."

Throughout the military utility assessment, the ACTD platoon leader kept the enlisted MAV operator under his direct control. He later concluded the unit could work more efficiently without detailed instructions. Dr. Tousley explains, "That was too much control required of him personally. He would never do that in the future, particularly in contact with the enemy."

What Next?

Soldiers of the 25th Infantry Division also provided a list of 50 MAV items for correction or improvement. Users want endurance of the vehicle doubled to about 45 minutes. They also want more battery life in the MAV ground stations. Faster GPS alignment is desired to shorten launch time. Honeywell is already working on the software changes.

Military users also identified the need for better vibration isolation and an optical zoom on the forward- and down-looking MAV cameras. The interchangeable day TV and night infrared cameras were selected by DARPA and the Army Night Vision Lab and came to Honeywell as Government Furnished Equipment. The sensors can be swapped in seconds, and the vehicle knows automatically what type of camera is in place. The second ACTD will use improved cameras in essentially the same T-MAV air vehicle.

The D-MAV heavy fuel engine promises fuel consumption about half that of a gasoline engine, but design of a 4 lb, 4 hp diesel engine had to start from scratch. Honeywell selected a winning design among three contenders last year, but ground tests in October showed the objective engine still not ready for integration into the vehicle for the follow-on ACTD. "We had to make a hard decision on a gasoline engine," acknowledges Dr. Tousley.

The heavy fuel engine remains in development by Greg Stephenson Engineering in Nevada. Honeywell should begin testing a revised configuration this spring and expects to fly the D-MAV around October of 2006.

Army private of the 25th Infantry Division assembles a micro air vehicle system during an experimentation exercise at a Schofield Barracks, Hawaii Military Operations in Urban Terrain site. (U.S. Army photo)

With its better thrust-to-weight ratio, the D-MAV should weigh 13.5 lb dry or 15 lb with full fuel and carry a slightly larger payload.

Honeywell will also grow the ducted fan for the FCS Class II vehicle. After a Preliminary Design Review last autumn, DARPA down-selected Honeywell and Aurora Flight Sciences to proceed with the Organic Air Vehicle (OAV) II competition. The second phase ends with a down-select in March or April based on a Critical Design Review with collision avoidance technology now flying on a surrogate vehicle. The OAV will be similar to the MAV. "All the lessons learned on the MAV activity have been incorporated into that vehicle," says Mr. Fulton. However, he notes the MAV and OAV are not identical. "The technology scales, but only to a point."

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