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Miniature UAVs

Flight Management Systems

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Miniature

By Bill Carey

Unmanned aerial vehicles (UAV) that can be contained in a backpack or even in the palm of your hand promise to deliver new intelligence-gathering and surveillance capabilities from the platoon level down to the individual soldier. These miniature aircraft gradually are taking their place at the far lower end of the rapidly growing UAV field.

With a research and engineering backdrop of more than a decade by various organizations, micro air vehicles (MAV) like the AeroVironment Wasp and Honeywell MAV are being evaluated in the field by U.S. military services. Further down the road in development, and orders of magnitude smaller, nano air vehicles (NAV) are at the conceptual design stage, facing unprecedented challenges in aerodynamics, propulsion and systems integration.

"The functionality of the micro air vehicle at the 100-to-150-gram scale has improved enormously," said Darryll Pines, chairman of the Department of Aerospace Engineering at the University of Maryland in College Park, Md. Work on NAVs, he said, has "pushed into even more fundamental physics problems associated with bio-inspired flight, where insects and small birds live."

Pines said a workshop conducted by the Defense Advanced Research Projects Agency (DARPA) and contractor Rand Corp. led to the beginning of a MAV program in 1994. The notional dimensions of such an aircraft, with a 6-inch wingspan and gross takeoff weight of 100 grams (3.5 ounces), were possible because of advances in microelectronics that made it feasible to build something at this scale.

The first years of the effort produced

Air Vehicles

From left to right, Lockheed Martin NAV, Draper Laboratory NAV, AeroVironment Wasp, Honeywell MAV

At the far lower end of the fast-growing UAV field, Nano and Micro Air Vehicles will give the warfighter new surveillance capability

some interesting configurations, he said, but not the performance numbers developers hoped to achieve. This spurred a "huge interest" in academia in the mid-to-late 1990s to crack the physics problems associated with a miniature air vehicle. Foremost was managing airflow at low Reynolds number — the ratio of inertial to viscous forces in the air, taking into account the speed and length of the vehicle.

"They had entered into a regime of flight called low Reynolds number aerodynamics that really was not truly understood," Pines said. "We got into a regime of flight where the flow physics resulted in highly viscous forces across wings and airfoils and led to large-scale flow separation and highly vortex generated flow. … The academic community had never really explored this turf, so it opened up a whole window of exploration into aerodynamic physics and designs and wing designs and rotor designs and just understanding [flight] at low Reynolds number."

In 2003, DARPA awarded Honeywell a contract to develop a ducted-fan MAV, which uses a propeller, contained in a duct, to draw in air and provide lift. Measuring 13 inches at its outside diameter, the vehicle flies like a helicopter and is fully autonomous; the operator can program a mission with up to 100 waypoints. Creating a vehicle of this size with complex flight controls, and keeping it stable in flight, was made possible by recent advances in microelectromechanical systems (MEMS), based on micrometer-sized machinery, said Vaughn Fulton, Honeywell's MAV program manager. The "heart" of the vehicle's avionics suite is a MEMS inertial measurement unit, he said.

Honeywell also "borrowed heavily"

AeroVironment Goes Public

Photo courtesy DARPA

AeroVironment's debut on the Nasdaq exchange Jan. 23 was the best-performing of three initial public offerings in the aerospace industry the previous year.

Shares in the Monrovia, Calif.-based developer of unmanned aircraft systems (UAS) rose 41 percent to $23.93 from the company's initial offering of 6.7 million shares at $17 each. That beat opening-day gains of 11.5 percent by Spirit AeroSystems last November and 14.8 percent by TransDigm Group in March 2006, Dow Jones MarketWatch reported.

AeroVironment was founded in 1971 by physicist and engineer Paul MacCready. The company in 2001 launched two product lines based on its small, Pointer UAS and PosiCharge electric vehicle starter. It now offers several small UAS platforms: the Raven, Dragon Eye, Puma, Wasp (above) and Swift. It reports churning out 200 aircraft per month from its Simi Valley, Calif., manufacturing facility.

In a filing with the Securities and Exchange Commission, AeroVironment reported fiscal 2006 revenue of $139 million, up from $32 million in FY02. The company said it nearly doubled the number of its employees from January 2004 through October 2006. It now employs 447 full-time workers.

AeroVironment in FY06 spent $16.1 million, or about 12 percent of revenue, on research and development.

"The market for our small UAS has grown significantly due to the U.S. military's post-Cold War transformation, the demands of the global war on terror and the tactical limitations of larger UAS," the company stated. "…As we explore opportunities to develop new markets for our small UAS, such as border surveillance and petrochemical industry infrastructure monitoring, we expect further growth through the introduction of UAS technology to non-military applications."

systems it developed for a range of aircraft, including the CH-47 and OH-58D helicopters, to build the MAV, as well as the turbojet, nacelle and associated airflow dynamics expertise of its engines business, Fulton said. "It's got a suite of avionics that are very similar to avionics applications for small civilian aircraft. It's got a fully functional flight management unit, a MEMS inertial system built by Honeywell, a Global Positioning receiver, a baro altimeter and a set of air-

Operator Control Unit and Ground Data Terminal of the Honeywell Micro Air Vehicle.

Photo courtesy Honeywell

mix all those together and it comes up with a very robust navigation solution," said Fulton.

The vehicle has interchangeable, forward and downward looking electro-optical (EO) and infrared (IR) sensors, which can be swapped out by changing payload pods, "about a 15-second exercise," said Fulton. A command and control radio frequency link using either military or civilian (900 MHz) bands sends commands up to the vehicle and status information down. An analog video link transmits real-time video.

A MAV system as specified by DARPA consists of two air vehicles — one equipped with EO pod, the other with IR pod. An individual carries one air vehicle. Other system components are a ruggedized tablet PC that serves as the Operator Control Unit (OCU), and a Ground Data Terminal (GDT) with companion uplink/downlink radios to interface with the OCU and vehicle.

The OCU, GDT and a manual starter fit into the U.S. Army's backpack system known as Modular Lightweight Load-carrying Equipment. The MAV system typically is divided among two soldiers.

Honeywell first delivered a TMAV, or transitional MAV, to validate the aerodynamic performance and flight controls of the vehicle. Testing by the U.S. Army's 25th Infantry Division at Fort Benning, Ga., and Schofield Barracks on the island of Oahu, Hawaii, in 2005, led to development of the GMAV, a gasoline-powered variant. The weight of a GMAV is 16 pounds dry and 18 pounds with fuel. The GMAV doubled the endurance of the vehicle to 50 minutes at sea level and made other improvements in advance of a formal military utility assessment (MUA). The Army conducted the MUA last October. "That was a very successful event, and they determined there's certainly military utility in a vertical takeoff and landing, 'hover and stare' capable system," Fulton said.

Less successful was an effort to develop a heavy fuel engine for the MAV, conforming with the military's single-fuel concept.

"The gasoline engine [on the MAV] is a four-horsepower engine that weighs about four pounds. That was generally the requirement for the heavy fuel engine," Fulton said. "That's a difficult technology proposition. There are no very small diesel engines out there at the moment, and so that development continues. It did not mature as fast as the basic VTOL [vertical takeoff and landing] capabilities of the system, so now they're kind of on separate paths."

The Honeywell MAV now is involved in a two-year extended user evaluation, the final phase of the DARPA program. The 25th Infantry Division will retain MAV systems built under the contract to develop operational concepts and tactics for the vehicle at the platoon level.

At this writing, Honeywell had logged more than 2,000 untethered flights with the TMAV and GMAV variants, and probably twice that number of tethered flights at its Albuquerque, N.M., testing facility, Fulton said.

He estimated the military had conducted some 500 flights independent of Honeywell. The company had delivered five TMAV systems —10 vehicles total — and 10 of the planned GMAV systems. Deliveries to the 25th Infantry Division were ongoing under the DARPA extended user evaluation.

Honeywell's maturation of the ducted-fan MAV led to another contract award under the Army's Future Combat System (FCS) program. Boeing, as lead systems integrator, and partner SAIC last May awarded Honeywell Defense and Space Electronic Systems a $61 million contract to develop the program's Class 1 UAV. The smallest of four planned UAVs under

Honeywell MAV

Photo courtesy Honeywell

- Mission: Detect and recognize man-sized target at 250 meters day, 125 meters night.
- Payload: Forward and downward looking EO and IR imaging sensors. Air vehicle stores 10 minutes of sensor imagery; ground station stores 60 minutes.
- Performance: 40 minutes endurance at 5,500 feet; 25-foot per second rate of climb; 50-knot airspeed.
- Communications: 10-kilometer range with military UAV frequencies.
- Flight Modes: Autonomous with dynamic retasking and manual intervention; hover and stare; remote launch.

the FCS umbrella, Class 1 calls for a small, "backpackable" UAV with hover and stare capability.

A preliminary design review is planned in the second quarter this year. First prototype deliveries and flight tests are slated for December 2008.

FCS is described as a "system of systems" that rests on four pillars: a common operating environment supporting multiple, mission-critical applications simultaneously and independently; "Battle Command" software enabling full interaction of FCS-equipped units; a communications and computer network providing secure, reliable access to information over extended distances; and a distributed, networked array of intelligence, surveillance and reconnaissance systems and sensors.

The FCS Class 1 vehicle would be the third variant of the Honeywell MAV.

The company has yet another contract from the U.S. military's Explosive Ordnance Disposal joint office, which is eyeing the MAV for its bomb-disposal mission. Late last year, the vehicle, representing the fourth variant, was undergoing an operational test phase at China Lake, Calif.

Warfighting Wasp

Another DARPA-developed MAV undergoing evaluation by the military is AeroVironment's Wasp, which is powered by a structural battery combined with its wing. The vehicle has a 16-inch wingspan, weighs about one-half pound and fits in a backpack.

The Wasp is hand or bungee-launched by a single soldier, has an operational range of 2 to 4 kilometers, an operational altitude of 50 to 500 feet above ground level, and can fly in excess of an hour at 35 miles per hour, DARPA says. Its ground control station is compatible with AeroVironment's small Raven and Pointer UAVs.

The Wasp payload consists of two color video cameras (forward and side-looking), a GPS receiver, altimeter, compass and air speed sensor. Designed for front-line reconnaissance and surveillance over land and sea, at the company level and below, the vehicle is being evaluated by the U.S. Navy and Marine Corps., and has been used in the Iraq theater.

The Nano challenge

Pines was assigned to DARPA from 2003 to 2006. In 2003, he initiated the agency's NAV program to push air vehicle technology to an even smaller scale.

Whereas the term micro air vehicle was derived from integrating MEMS devices, nano air vehicle — a term coined by a colleague — is somewhat of a misnomer, Pines said, and does not refer to nanotechnology.

"It's an interesting feature of insects, if you look at the microstructure of their wings, the physical structures are on the order of 50 to 100 nanometers in scale length," he said. "The nano structural elements within the insect's wing are very important to its performance. That's really how I leveraged the term 'nano,' in terms of air vehicle."

The biggest challenge to developing an air vehicle that could reside in the insect world is "efficiency in power conversion, whatever the power source is, through the mechanical transduction to the ability to generate lift and thrust," Pines said.

"The other part is in the aerodynamic efficiency, to generate effective lift at this small scale of flight. The combination of the two being efficient makes the system efficient, and then has to be combined with the system design process to make sure that any integrated functionality like sensors and communication are not drawing too much power, to make [the vehicle] not viable," Pines said.

DARPA solicited proposals for the NAV program in 2005 and awarded contracts last year. The agency specified an air vehicle with a maximum dimension of 7.5 centimeters in any axis, weighing 10 grams or less, and capable of 20 minutes endurance and 1-kilometer range. The UAV's mission would be "urban" and often indoors.

Photo courtesy Lockheed Martin

Lockheed Martin Advanced Technology Laboratory proposes a mapleseed-shaped air vehicle powered by a chemical thruster for DARPA's NAV project.

"The program will advance technologies that enable collision avoidance and navigation systems for use in GPS-denied indoor and outdoor environments and develop efficient methods for hovering flight and deployment or emplacement of sensors," DARPA said.

Four concepts are being developed under the NAV conceptual design and risk reduction phase: flapping-wing designs by AeroVironment, Monrovia, Calif., and MicroPropulsion Corp., of Oakland, Calif.; a coaxial rotorcraft by Charles Stark Draper Laboratory, Cambridge, Mass.; and a mapleseed-shaped vehicle by Lockheed Martin Advanced Technology Laboratory (ATL), Cherry Hill, N.J. The organizations at this writing released varying degrees of information on their NAV projects. AeroVironment, which was readying for an initial public offering, declined to elaborate. MicroPropulsion referred questions to DARPA.

The mapleseed NAV being developed by Lockheed Martin ATL under a $1.7 million contract will be powered by a chemical thruster enclosed in its one-bladed wing. The vehicle will be about 1.5 inches (3.8 cm) long, with a maximum takeoff weight of about 0.35 ounces.

It is expected to carry an interchangeable sensor payload module weighing 0.07 ounces for a distance of 1,100 yards, or about 1 kilometer.

In addition to controlling lift and pitch, the one-bladed wing will house telemetry, communications and navigation functions, imaging sensors and battery power, the company says.

Partners in the effort are Lockheed Martin's Advanced Development Programs (Skunk Works) and Advanced Technology Center. Sandia National Laboratories, managed by Lockheed Martin, is providing expertise in microfabrication of materials and actuators. ATK Thiokol, Edina, Minn., is providing propulsion technology; the University of Pennsylvania is developing flight-control algorithms; and AeroCraft Consulting, Portland, Maine, is responsible for detailed aerodynamic design.

As of December, the team had completed a conceptual design review, and was planning to conduct risk reduction demonstrations by the end of the 10-month base contract in April, said Steve Jameson, Lockheed Martin's NAV program manager. The company expects to execute an eight-month option after that, culminating with a preliminary design review by the end of the year.

A second phase of the program in 2008 would entail building and flying a complete prototype.

"The biggest challenges we're facing are on the mechanical, or physical [side] as opposed to the software," Jameson said. "There are significant aerodynamic challenges to getting a vehicle like this to fly stably. Assuring ourselves that it will work has been a challenge simply because of the lack of existing design tools. Design tools do not exist off the shelf to enable high-fidelity analysis of a vehicle of this scale."

One of the objectives of the DARPA program is to foster the development of design tools, and that is another aspect Lockheed Martin is addressing with its NAV project, Jameson said.

Control device

At this point, less emphasis has been placed on the handheld device an operator will use to control the NAV. Lockheed Martin is looking to commercial industry for a solution there.

"We have not done a specific design for [a control device] because we are focused at this point on the high-risk portions, and we believe that is a relatively low-risk portion," Jameson said.

"The commercial gaming industry has invested billions of dollars in the development of easy-to-use, highly effective handheld controllers for real and simulated vehicles, and we intend to make maximum leverage of that. We don't expect that we're going to be putting a lot of effort into building something from scratch."

The NAV is expected to have a processor on board that will be capable of some degree of flight controls. However, the NAV will not have an embedded autopilot, as the vehicle is not required to fly autonomously.

The project also does not address operating the NAV within an insect-like "swarm" or as part of a cooperative group — concepts studied by the Air Force and Navy research laboratories. Lockheed Martin is looking at that separately.

"Independent of the DARPA contract, we are doing a lot of thinking about applications such as having groups that will operate as a swarm, and what might be done with that," Jameson said.

"The DARPA contract is solely to get a single platform working under remote operator control. That in itself is challenging enough," he added. "But we are separately doing a lot of thinking, both in terms of autonomous operation of a single platform and autonomous or semi-autonomous operation of teams of platforms," Jameson said.

Draper Laboratory is developing a dual-blade, coaxial rotorcraft design with a centrally located lithium-ion battery and avionics.

As systems integrator, Draper will lead the design of the avionics, propulsion and guidance, navigation and control subsystems, leveraging its guidance algorithms and ultra-dense packaging to provide a 3-gram flight control package.

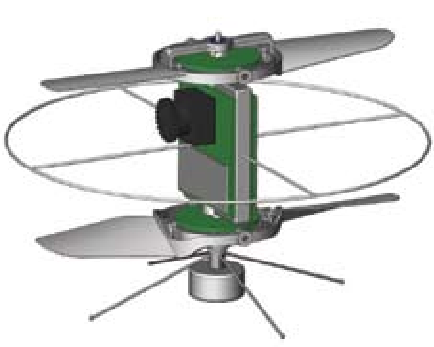
Its partners include the Massachusetts Institute of Technology Department of Materials Science and Engineering, providing miniature Lithium-ion battery technology; and Daedalus Flight Systems, Rockville, Md., providing aircraft design.

"At this scale, the aerodynamics is a huge challenge, just because we're working in very low Reynolds number regimes. That just makes it much more challenging, particularly for rotary-wing vehicles," said Paul Samuel, president and CEO of Daedalus.

"Designing for these sizes and regimes also requires rotor blades that are very small, very thin. Everything's a trade-off. You can make your rotors more efficient, but you end up needing rotors that are so thin that you can't physically manufacture them, or if you do manufacture them, they're so floppy that they can't hold their shape," he said.

Samuel described other technological hurdles involving the airframe and propulsion.

"A lot of what we're trying to do is use the electronic components as the aircraft



Draper Laboratory is developing a dual-blade, coaxial rotorcraft design under the DARPA Nano Air Vehicle Program, powered by a centrally located Lithium-ion battery.

Illustration courtesy Draper Laboratory

structure. One thing that's very popular to do is use lithium polymer batteries as part of the airframe. But they tend to change size as they're used," he said.

"A bigger problem has to do with motor integration. Electric motors tend to want to spin very fast, but rotors want to spin very slow for efficiency."

Is there a point at which the miniaturization of aircraft stops being practical?

"I think there is a limit," said Pines.

"For instance, going to something that is, say, a few hundreds of milligrams. It's not practical, because at this point you would require an enormous leap in technology to find some useful sensor. However, if you get to about 10 grams or five grams or even a couple of grams, you can still do something useful. You can develop MEMs-based sensors that don't weigh very much. There are optical sensors that weigh half a gram, and the payloads can be at a gram scale.

"At a 10 gram gross takeoff weight, you can do some practical things," Pines said. avs