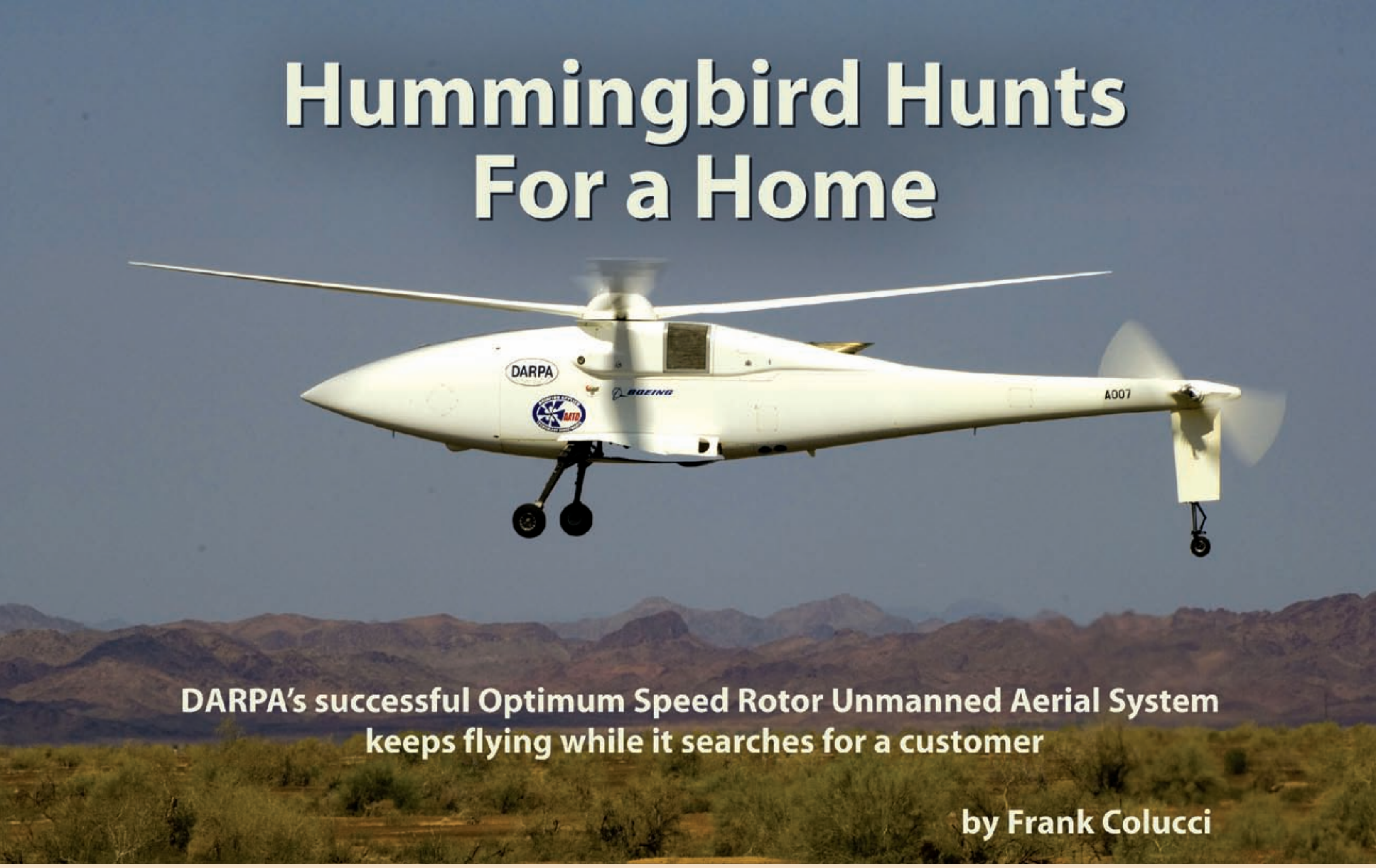
Hummingbird Hunts For a Home



DARPA's successful Optimum Speed Rotor Unmanned Aerial System keeps flying while it searches for a customer

by Frank Colucci

The Boeing A160T flew for 18.7 hours on May 14-15, 2008, satisfying the last requirements of a DARPA Advanced Concept Technology Demonstration and laying claim to an unofficial world endurance record for Unmanned Aerial Vehicles weighing between 500 to 2,500 kg.

With 18.7 hours unrefueled endurance, ability to Hover Out of Ground Effect at 15,000 ft, and a 600 nm range with a 1,000 lb payload, the Boeing A160T Hummingbird has demonstrated remarkable rotorcraft performance. The Defense Advanced Research Projects Agency (DARPA) nevertheless waits for a military customer to transition the Vertical Takeoff and Landing (VTOL) Unmanned Aerial System (UAS) to production. Phase 1 of the 30-month A160 Advanced Concept Technology Demonstration concluded in July with a close-out briefing to the Department of Defense. DARPA director Dr. Anthony J. Tether subsequently extended the effort through January 2009 under a bridge contract that further expands the Hummingbird flight envelope and integrates the innovative helicopter with advanced sensors. "His intent is DARPA should become a user of the A160 rather than a developer," explains A160 Program manager Phil Hunt in the DARPA Tactical Technology Office.

The Optimum Speed Rotor (OSR) demonstrator with its sizeable payload remains a versatile test platform. The Affordable Adaptive Conformal Electronically scanning array Radar (AACER) with synthetic aperture and moving target indicator functions flew on the Hummingbird in February. This summer, Hummingbird No. 11 began carrying a 21 ft long antenna for the Foliage Penetration Reconnaissance, Surveillance, Tracking and Engagement Radar (FORESTER). A Hummingbird hovering in a headwind at 15,000 ft gives the UHF radar zero ground speed to spot slow-moving, low-Radar Cross Section targets through trees. With landing gear retracted, the unmanned helicopter affords the rotating antenna an all-round field of regard. A Hummingbird fuel fraction around 50% also provides endurance for persistent wide-area radar surveillance. "You've got this incredible synergy between this very effective new sensor and this aircraft which can accommodate it," observes Mr. Hunt.

The Hummingbird "bridge" also gives the DARPA Information Exploitation Office a chance to test the Autonomous Real-time Ground Ubiquitous Surveillance – Imaging System (ARGUS-IS) in early 2009. The 1.8 gigapixel video sensor and its airborne processor will fit aboard Hummingbird No. 9 with an 11 ft long cargo pod. Meanwhile, the program extension keeps Hummingbird No. 7 flying with an upgraded L-3 WESCAM MX-15D day/night laser-designating electro-optical payload to refine the A160T itself. According to Mr. Hunt, "We're going to use that time as well to develop a little bit further the reliability."

The crash that claimed Hummingbird No. 8 in December 2007 was blamed on a family of possible causes. "We attacked all of them with the architecture we have," says Boeing program manager Jim Martin. A160T flights resumed in March 2008 with the existing single-string fly-by-wire flight control system. The Hummingbird will upgrade to dual flight processors and navigation units this fall. Dual redundant flight control actuators are in later plans.

DARPA's Advanced Concept Technology Demonstration proved the efficiency of the OSR and advanced the Hummingbird from the piston-engined A160 to the turboshaft A160T. "What we've gotten out of that is a body of understanding and an ability to go forward which is vested in Boeing," says Mr. Hunt. Shared funding for the ongoing effort comes from DARPA, the Army Aviation Applied Technology Directorate (AATD), and Boeing. Mr. Hunt says, "What everybody is trying to do, who sees the value in the program, is to create the space for the A160 to prove it is in the right place."

The flight-configured A160T Ground Test Vehicle in Irvine has run simulated missions longer than 20 hours duration. Ship 6 has also changed gears to demonstrate Optimum Speed Rotor technology.

Right Place, Tough Time

Boeing acquired Hummingbird rights and hardware with inventor Abe Karem's Frontier Systems, Inc. in May 2004. The original Memorandum of Agreement between DARPA and the US Army aimed to transition the A160 to production in 2006. The Future Combat Systems schedules nevertheless made the Northrop Grumman MQ-8B Fire Scout the Class IV upper echelon VTOL UAS for the Army, and left the Hummingbird looking for a startup customer.

Under a Naval Air Systems Command contract, the Boeing Advanced Rotorcraft rapid prototyping facility in an Irvine, California office park is building seven Hummingbirds for the US Special Operations Command. With reliability improvements and Beyond Line Of Sight datalinks, the SOF Long Endurance Demonstration (SLED) aircraft may drive an A160T production decision in 2009. Boeing flew the A160T at speeds to 79 kt with a 1,090 lb cargo pod for Special Operations, and the company expects to fly the Hummingbird with Hellfire stub wings this year. The A160T offers a suite of advanced rotorcraft technologies to other government users. "What makes an A160 an A160 is more than the OSR itself," notes Mr. Martin.

The A160T external cargo pod measures 19 by 30 by 130 inches and carries 1,000 lb. The A160T also has external attachment points for cargo hooks, winches, and payloads.

OSR technology appealed to AHS Klemin Award winner Abe Karem as a way to shrink the gap between the loiter efficiencies of fixed- and rotary-wing aircraft. As then-president of the aero-engineering firm Matoss in Israel, Mr. Karem suggested a fixed-wing UAS with more than 24 hours endurance in 1974. His target customer wanted something compact that could operate alongside soldiers in the field. [Karem's fixed-wing UAS was eventually developed into the MQ-1 Predator.]

For a VTOL UAS free of runways, varying rotor speed with airspeed, altitude, weight, and load factor promised to increase lift-to-drag ratios and extend endurance. Conventional helicopters vary rotor speed safely over only a narrow band. (The Bell 407 range, for example, is between 92% and 107% of nominal value.) To vary speed over a wider range yet avoid dynamic resonance with the airframe, an Optimum Speed Rotor required very rigid, light blades.

In 1997, DARPA sought an unmanned vehicle to fly

The Optimum Speed Rotor varies rpm over 50% to enhance lift/drag ratios and extend endurance. The A160T ACTD progressed through 2-, 3-, 5-, 8-, 12-, and 18-hour endurance gates to meet DARPA requirements.

Boeing has developed stub wings to arm the A160T.

missions up to 40 hours duration with a 300 lb payload. Abe Karem's Frontier Systems offered a diesel-powered OSR concept. DARPA recognized the risk in variable speed rotor technology. However, the NASA/Army aeromechanics team at Ames Research Center used the then-new CAMRAD II analysis tool on the preliminary OSR design and concluded the rotor could indeed operate fully lift-loaded over a wide speed range. Mr. Karem summarizes, "We take the mass out of the blade and add stiffness, and it works." Karem Aircraft today aims its Optimum Speed Rotor technology at the military Joint Future Theater Lift (JFTL) and commercial TR53 tilt rotors.

The third and fourth OSR designs flew successfully on the A160 starting in 2002. The Hummingbird reduces main rotor speed up to 50% – from 400 rpm on takeoff to 200 rpm in long-endurance cruise – to minimize induced and profile drag. OSR payload in cruising flight is about 50% greater than a conventional rotorcraft in the same conditions. A side benefit of slowing the main rotor down is an acoustic signature about one-quarter that of a Bell 407. AATD plans to take formal acoustic measurements on the A160T in 2009.

The 36 ft diameter hingeless Hummingbird main rotor has four all-composite blades with a high natural frequency to avoid resonance issues. "They don't droop," notes Mr. Martin. "It's the stiffness of the system that allows us to decouple the rotor input from the fuselage." The fixed main rotor mast also provides a home for the Beyond Line Of Sight satellite antenna in upcoming communications on-the-move demonstrations.

Hummingbird flight control hardware was designed and built in Irvine by Frontier and Boeing. The brushless main rotor actuators weigh just 8 lb each. The 58 lb main rotor blades with their proprietary airfoils and tapering tips give the current A160T a disk loading less than 6 lb/sq ft. "That particular characteristic contributes to our long range," says Mr. Hunt. In October 2007, the A160T used just 60% of its on-board fuel to cover 960 km (520 nm) in 12.1 hours with a 1,000 lb payload. The 18.7-hour endurance demonstration at Yuma Proving Grounds in May was flown with a 300 lb payload. "When we landed there, we had the capability of going a bit longer," observes Mr. Hunt. The flight-configured Hummingbird Ground Test Vehicle – Ship 6 – has simulated missions longer than 20 hours in the test cell.

Rotors Plus

The first and second A160s accumulated about 250 flight hours with their four- and six-cylinder Subaru gasoline engines, and they varied rotor rpm by changing engine speed. The four-cylinder Hummingbird achieved 12 hours endurance. A diesel engine promised safer, more efficient power for the objective 32 hours endurance. However, with development of a Hummingbird heavy-fuel engine trailing the air vehicle in 2006, DARPA authorized a more powerful but more conventional turboshaft substitute. "The challenge of developing a new airframe and a new diesel was too great," concludes Mr. Hunt.

The Maverick autonomous UAS demonstrator helped develop flight control technology for the Hummingbird and experimented with UAV operating concepts.

The Opposed Piston/Opposed Cylinder diesel under development by FEV promises specific fuel consumption around 0.37 lb/hp. Typical turboshaft fuel efficiency is around 0.53 lb/hp. Heavier and bigger than a turboshaft, the objective heavy-fuel engine remains under study with an eye to multiple platforms.

Boeing first flew the A160T with an unmodified Pratt & Whitney Canada PW207D turboshaft, fully digital flight controls, and an upgraded but still conventional tail rotor in June 2007. Compared to the reciprocating engines, the turbine effectively doubled Hummingbird performance. The off-the-shelf turboshaft is rated 572 shp continuous or 676 shp in emergencies, and it is certified to 20,000 ft altitude. The A160T has hovered briefly at 20,000 ft, and altitudes to 30,000 ft are possible. Though the diesel promised 32+ hours endurance at 15,000 ft, the turbine provides 20 hours at the same altitude and higher speeds. Maximum speed so far has been 146 kt. Mr. Hunt says, “That is probably not something you’re going to break records with, but it is significant.”

Free turbines are nevertheless most efficient running at constant speed, so the A160T introduced a two-stage planetary gearbox to reset the main rotor baseline at 50 or 100% nominal rpm. Though all A160T missions so far have been flown only at low rotor speeds, the tethered Hummingbird No. 6 has changed gears several times in the Irvine test cell. DARPA plans to do the first in-flight gear change in September.

The Hummingbird blends the rigid rotor with a low-weight, low-drag graphite epoxy airframe that remained unchanged in outline from the piston A160 to the turbine A160T. The main rotor driveshaft and tail rotor blades are likewise composite. Hummingbird takeoff weight with a 300 lb payload is around 5,300 lb, and with a 2,400 lb empty weight, the A160T enjoys a fuel fraction greater than 50%. By comparison, Boeing calculates the UH-60 Black Hawk fuel fraction is around 22%. The 18-hour endurance flight also demonstrated an unrefueled range around 1,800 km range, but according to Mr. Hunt, “We think we can do more. We think we can do 2,200.”

The 400 gal of fuel in the A160T is contained in four cells around the center of gravity. The composite-skinned fuselage also offers large bays fore and aft of the main rotor, a large replaceable nose fairing, and tail boom space for payloads. Flight instruments are air cooled, but the Hummingbird provides liquid cooling for power-intensive payloads. Engine airflows are routed to diffuse the A160T infrared signature.

The digital fly-by-wire flight controls of the A160T grew out of work done by DARPA and AATD with the analog Maverick UAS. The unmanned Robinson R22 logged about 500 flight hours and demonstrated autonomous flight control. The A160T flies its missions autonomously, albeit with a safety pilot in the loop at a Ground Control Station developed by Frontier. “We do recognize the Army One system or Navy TCDL,” notes Mr. Martin. The six-cylinder Hummingbird first demonstrated automatic return to base after a simulated loss of communications, and showed mission plans could be changed in flight.

Most Hummingbird flight testing has been conducted at Victorville, California. Though the four-cylinder A160 made some rolling takeoffs, all flights of the turbine-engined A160T have begun and ended vertically. The vibration environment aboard the rigid rotor Hummingbird is unexceptional. “We didn’t expect it to be any different from a normal helicopter,” says Mr. Martin.

Beyond the DARPA “bridge,” the Army Aviation Applied Technology Directorate (AATD) will run an A160T modeling and flight test effort through Fiscal 2010. “We’re characterizing the performance of the aircraft throughout its entire flight envelope to really understand the benefits of the Optimum Speed Rotor and other features,” says David Friedmann, rotors team leader in the AATD Platform Technology Division. Data collected so far will refine the A160T aeromodels, and Hummingbird No. 7 will validate the models in high-blade-loading flight. Mr. Friedmann notes, “I’ve been with the program quite awhile, so I’m beyond being awed. It’s got incredible capability and with the amount we’ve tested so far, it’s lived up to what they said it would do.”

The operational potential of the A160T remains significant. Two Hummingbirds could deploy aboard a C-130 transport, and Boeing has discussed communications relay, electronic intelligence, and other missions with a range of potential users. However, for now, the A160T remains a test platform in search of a paying customer. Mr. Martin observes, “People have to think about how do you use this kind of capability.”

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