In Flight USA

Next-Generation Helicopters

Bernardo Malfitano

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Since the dawn of aviation, the idea of Vertical Take-Off and Landing (VTOL) aircraft has been appealing to engineers, pilots, and passengers. The convenience of an aircraft that can take off and land anywhere, without the need for a long flat runway, is undeniable. Who would not wish to fly an airplane that can hover like a balloon? Thomas Edison once said that “The airplane won't amount to a damn until they get a machine that will act like a hummingbird; Go straight up, go forward, go backward, come straight down and alight like a hummingbird”. One potential solution to this problem has been theorized since at least DaVinci’s time: Keep the aircraft in place while rotating lift-generating surfaces over it. Thanks in large part to Igor Sikorsky’s work starting in the 1930s, such aircraft today are commonplace. Over the past seventy years, the helicopter has come to dominate many niches in aviation such as search-and-rescue, law enforcement, news gathering, and transport of people and supplies to remote areas. Helicopters also play a major role in many other sectors of aviation, such as warfare, fire-fighting, VIP transport, and aeronautical research.

However, a helicopter does not have the flight endurance or the range of an airplane of equivalent size. Helicopters invariably use far greater amounts of fuel. The reason is not difficult to understand: The high lift-to-drag ratio of most airplanes means that their wings can overcome the aircraft’s weight at speeds where the drag force (and thus the necessary engine thrust) is significantly lower than the airplane’s weight. Only some fighter jets have a thrust-to-weight ratio higher than one (and they are not known for fuel efficiency, either). A helicopter’s engine and rotor, however, must produce a force greater than the helicopter’s weight in order to lift that weight off the ground. So a helicopter engine must always work harder than the engine of an airplane of the same weight. More thrust means quicker fuel consumption and thus lower range and endurance.

But two modern experimental helicopter programs aim to develop the technologies necessary to reduce this gap between airplane and helicopter performance. The X-50 Dragonfly and the A160 Hummingbird point towards a series of new solutions, only possible with modern materials and computerized controls, that might greatly expand what we come to expect from our rotorcraft.

The Boeing A160 Hummingbird is an Unmanned Aerial Vehicle (UAV) helicopter that first flew in 2002. It is 35 feet from nose to tail, weights 4300 pounds, and has a rotor diameter of 36 feet. Not a large helicopter, but it can fly at 140 knots and carry over 1,000 pounds in sensors or other payload. The US Army and Navy have helped to fund the project as research, and DARPA has an order for six Hummingbirds to be used as sensor platforms.

Over the past five years, Boeing's engineers have modified and replaced the Hummingbird's engines, improved its flight-control software, and modified its sensors and structures, to allow for longer endurance, greater range, and higher maximum altitudes. To anyone familiar with the limitations of current helicopters, the goals of the A160 project are almost unbelievable: 24-hour endurance, 30,000-foot altitude, and 2,500-mile unrefueled range. While working towards those numbers, the Hummingbird has already been flown for 17 hours, in a 1,200-mile course around its home airfield in Victorville, CA. A landing mishap at the end of this flight prevented it from being officially recognized as the longest unrefueled helicopter flight on record. A more recent flight lasted over 12 hours and used up less than 60% of the maximum fuel load of the Hummingbird. Some of these long flights were performed with pods simulating military sensor packages, weighing from 300 to 1,000 pounds. Boeing's next goal is to fly for 18 hours with one of these pods, at speeds and altitudes representative of military recon missions currently performed by fixed-wing UAVs like the Predator. These long endurance times put the Hummingbird in a helicopter class all its own. Helicopter operators everywhere are now asking themselves what helicopters could be capable of, once the A160's technologies find their way into production rotorcraft. The restricted range and high costs of current helicopter flight might have their days numbered.

These amazing endurance times are possible because of the many new technologies that drastically reduce the power needed to keep the A160 in the air. The first prototype, in fact, was powered by a 4-cylinder Subaru automotive engine, not nearly as powerful as the engines typically used to get helicopters of that size and weight off the ground.

How can the Hummingbird fly with so little power? Well, most helicopters fly with their rotors spinning at a fairly constant rotational speed. In thinner air, such as at high altitudes or during hot days, the collective blade pitch must be increased so that enough lift is generated. What allows the Hummingbird to use so little energy while holding itself aloft is its ability to significantly change the rotor's RPM during flight. Its rotor blades continually adjust not just their pitch but also their speed, seeking an optimal combination that provides just enough lift given the air around the helicopter, while minimizing the power needed from the engine.

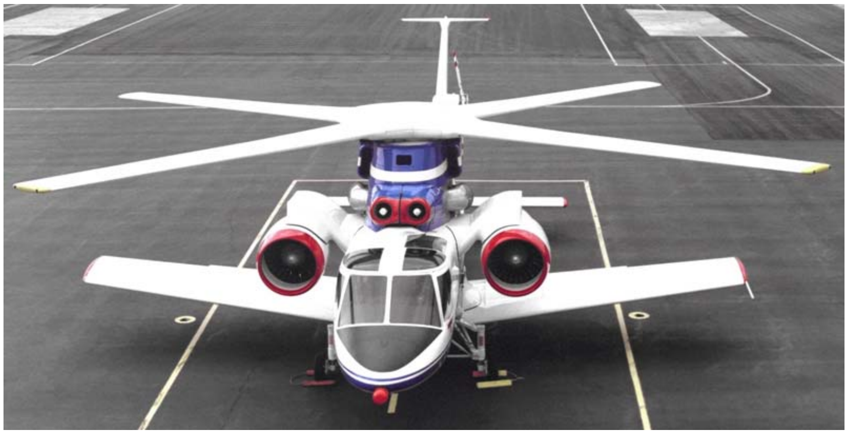
One might think that Boeing would work hard to keep such a secret from their competitors. However, optimizing rotor RPM is a fairly obvious solution when trying to minimize the necessary engine power in a helicopter. In fact, this optimization technology can be found publicly in patents, which Boeing has licensed. But changing rotor RPM continuously during flight is easier said than done. Like a jet airliner's wing, helicopter rotors work best when the tips are flying at a significant fraction of the speed of sound. Spin any faster, and the rotor tips break the sound barrier and effectively stop working, since shockwaves reduce lift and increase drag. Spin any slower, and the inboard sections of the rotors can stall, unless they are designed in unconventional ways so as to work under exceptionally low loading. Boeing pulls it off by having rotor blades with large surface areas, unusual airfoil curvatures, and exceptional torsional rigidity – enough rigidity, in fact, to do away with hinges and with many other moving parts found in current helicopter rotors. These design features, which allow the rotor to spin more slowly than those of most helicopters, are only possible thanks to the very latest in composite-material technologies. Boeing can use advanced techniques to design and build composite blades with unique curvatures and stiffness properties, and the company does not reveal the details about how this is done. This design gives the Hummingbird's rotor a greater range of RPMs to work with before the blades stall or approach the speed of sound. It also makes for significantly less noise than a conventional helicopter. On top of that, fewer moving parts means less friction in the rotor mechanisms, further reducing the necessary engine power. Incidentally, it also means a more reliable mechanism.

Once Boeing validates and further develops these technologies in the A160 Hummingbird program, the company will probably incorporate them into the design of their next helicopters. With the cancellation of the RAH-66 Comanche program, and the age of many helicopters in service with the US Army and Marine Corps, Boeing realizes that they can probably benefit from learning how to optimize the use of these technologies sooner rather than later.

While these new design techniques can potentially create helicopters with similar range, endurance, and maximum altitude as airplanes of equivalent sizes, they do not overcome another inherent limitation of the rotorcraft: speed. As a rotorcraft flies forward, rotor blades on one side move forward into the oncoming air, and blades on the other side retreat backwards along with the air. If the helicopter's flight speed matches the speed of the retreating blades, then they are not moving through the air at all, generating almost no lift. And a helicopter can only fly so fast before the advancing blades' tips approach the sound barrier.

For these reasons, over the past 50 years engineers have tried to create VTOL aircraft of a variety of non-helicopter configurations. These include tilt-rotors such as the V-22 Osprey, ducted-fan aircraft such as the Joint Strike Fighter, and thrust-vectoring jets such as the Harrier. Other techniques, such as large "bucket flaps" that direct engine exhaust downwards, or even landing the entire airplane onto its tail and having it take off nose-up like a rocket, have been developed over the decades and are used by many modern UAVs. However, one last VTOL configuration was not possible until recently, and another Boeing experimental helicopter has been built to explore it. This particularly challenging design is known as the rotorwing.

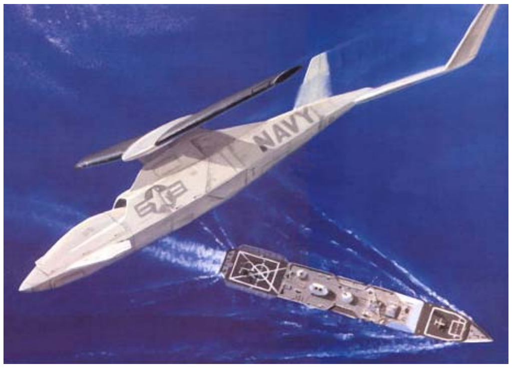
The idea is straightforward enough: When the aircraft reaches sufficient forward speeds, the rotor could be stopped, and the blades could act as fixed wings. But many serious problems are immediately evident: Once the rotors stop, the air may not be moving past them as fast as it was when the blades were spinning, so additional fixed-wing area will be necessary. Even worse, half the rotor blades (the ones on the retreating side) will be facing the wrong way once this transition happens. Those blades must either be rotated around, or have a symmetrical airfoil cross-section. If these problems could be overcome, then it should be possible to develop an aircraft that, like a tilt-rotor, combines the VTOL performance of a helicopter with the speed and range of an airplane. Noise, vibration, and maintenance needs could be reduced, relative to a conventional helicopter.



Sikorsky decided to investigate in the early 1970s. Funding from NASA and DARPA allowed for the development of the S-72, which eventually became the X-wing. It featured a conventional airplane's wings and jet engines, and also a helicopter's powered rotor and tail rotor. Maneuvers in pitch and roll were executed not by differential blade pitch but by mechanisms similar to blown flaps, where some engine exhaust was released over the rotor blades. Many flights were carried out, with different rotor systems and sometimes (in some fixed-wing flights) none at all. The prototypes flew in "airplane mode" many times, and in "helicopter mode" many times, but the program funding was ended before NASA could try to perform an in-flight transition.

One problem that prevented the X-wing configuration from becoming practical was its reliance on two entirely separate power systems: Jet engines for forward thrust, and turboshaft engines to spin the rotors. During helicopter flight, the jet engines are effectively dead weight, and during fixed-wing flight, the turboshaft is similarly useless. But how can a single engine create forward thrust and also spin a rotor? One option would be to have a shaft exiting the engine that uses some of the power to spin the rotor, similar to how the Joint Strike Fighter's engine powers a lift-fan. Another option would be to pipe exhaust or bleed air from the engine up through the blades and out the tips, pushing the rotors as this air is blown back from the blade tips. Many experimental helicopters, such as the remarkable Hughes XH-17, have flown using this tip-jet approach.

Recently, Boeing investigated this second possibility. Its Advanced Projects division saw a niche in the aerospace marked for aircraft of what they called the Canard RotorWing configuration, or CRW. Such an aircraft would have canards, a conventional tail, as well as a high wing, which could be spun like a rotor using engine air blown out the rotor tips. No tail rotor would be needed, since the rotor spins itself and thus does not exert an opposite reaction torque on the fuselage. During fixed-wing flight, all engine exhaust would exit the aircraft though a jet nozzle.



UAVs were successfully used during Operation Desert Storm. This generated interest in a high-speed tactical VTOL drone that could be operated from Navy warships such as destroyers, which cannot launch or recover conventional airplanes. Applications would include reconnaissance, target acquisition, and communications relay. The CRW's combination of jet-like speed with helicopter-like takeoffs and landings should make for an appealing platform for weapons and sensors.

Boeing persuaded DARPA about the promise of these cababilities, and thus was born the X-50 Dragonfly. This first proof-of-concept Canard-RotorWing is a tiny aircraft: Less than 18 feet long, with a rotor diameter/wingspan of under 7 feet, and weiging in at under 1,500 pounds. A stealthy B-2-like air intake is right at the nose, with a relatively large and slightly-swept canard at either side. Vertical stabilizers stick up from the outboard ends of a horizontal stabilizer, making for a U-shaped tail. In between, a tall hump houses the engine, and atop it sits the high wing that can be spun around as a rotor. The first X-50 was to have flown in 2001, but ground testing revealed high cyclic loads that required repairs to the rotor bearings, as well as use of steel instead of aluminium in some structural parts for added stiffness.

During vertical flight, engine exhaust was released by small nozzles near the rotor tips. This spun the rotor without the need of a transmission, gearbox, tail rotor, or the other mechanical complications found in rotors spun by engine torque. The lack of a tail rotor meant that changes in aircraft orientation were controlled by a Reaction Control System, i.e. by releasing engine bleed air out of small valves in the tail, similar to what is used in the AV-8B Harrier during hover. The X-50's wings did make for a stubby rotor, so they were set to a visibly high angle of incidence for vertical flight. During forward fixed-wing flight, engine air was to be released from a nozzle at the back of the hump. As for the transition, the air being released would gradually shift from the blade-tip nozzles to the main fuselage nozzle, and the canards and tail should provide significant lift while the rotor is being stopped.

Aviation enthusiasts have noticed that “X-50” was not the next designation in the X-plane sequence. Steve Bass, manager of the X-50 program, said that Boeing was able to get the out-of-sequence designation by special request “because the X-50 designation is so fitting for the CRW concept - 50 percent helicopter and 50 percent airplane”.

The US Marines showed serious interest in the project, and hoped to be able to fund the development of a manned CRW around 2012, to replace the venerable AH-1 Cobra.

Two prototypes were developed, designed, built, and tested in Mesa, AZ, home of the AH-64 Apache. First flight of the X-50 took place in November of 2003. In March of the following year, however, cross-coupling of the controls caused a crash that resulted in the loss of the first aircraft. Significant improvements were made to the second prototype before it flew. However, in April of 2006 at the Yuma Proving Grounds, Ship 2 was completely destroyed on its sixth of 11 planned test flights. Subsequent investigation revealed that the aircraft's fuselage was subject to an aerodynamic pitching moment of extreme sensitivity. Both airspeed and rotor wake would produce a nose-up pitching motion that was greater than the flight controls could compensate for.

It is unclear whether the CRW concept will be explored any further. The Marine Corps may be understandably unwilling to fund the development of a full-scale manned CRW, although the lessons learned during the X-50 program show that one could theoretically be built, as long as the control systems are powerful enough to overcome some of the unique loads experienced by such unusual aircraft.

Boeing’s other experimental rotorcraft, however, is still showing great promise. Recently, a second Hummingbird crash involved the new turboshaft-powered version, but this will only slow down the program until the next prototype is finished, and that should not take long. Keep an eye out for the announcement of record-breaking helicopter flights involving a sleek teardrop-shaped UAV in Victorville, CA.

The technologies being developed in the A160 program, as well as during development of the V-22, are leading us to expect more of our rotorcraft. Today, VTOL aircraft such as helicopters do not have the range, speed, payload, or efficiency of fixed-wing aircraft. They are much more complex mechanically, and use significantly more fuel. But the causes for this gap are being deconstructed and slowly solved by some of the brightest aerospace engineers around. Soon rotorcraft will overcome many of their limitations, and will become an even greater part of the everyday aviation world. The next revolutionary VTOL idea might be just around the corner, and the aerospace giants seldom miss the opportunity to explore a promising new idea. So stay tuned!