Imagine a time in the not-too-distant future when unmanned vertical takeoff and landing (VTOL) aircraft stealthily cross urban battlefields and quietly touchdown in confined areas inaccessible to conventional helicopters or winged VTOL aircraft.

For the past 20 years, developing internal ducted rotocraft has been the passion and profession of a team led by Dr. Rafi Yoeli, the founder and CEO of Urban Aeronautics Ltd, an Israeli company based in Yavne, 20 miles (30 km) south of Tel Aviv.

UrbanAero is designing, manufacturing and marketing Fancraft, its family of multi-mission VTOL vehicles without external rotors.

Yoeli designed, built and flew the Hummingbird, a single ducted flying platform in the mid-1990s (see sidebar) when he was running Aero Design & Development (AD&D). The company’s main business was providing aeronautical engineering consulting services to defense and aerospace companies, covering the civil and military fixed-wing, rotary-wing and unmanned aerial vehicle (UAV) sectors.

After he sold his shares in AD&D to Elbit Systems in 2003, Yoeli founded UrbanAero to develop a modern-day successor to the 1950s tandem internal rotor Piasecki VZ-8 AirGeep. The first focus for the twin-fan design was on the civil market, but the US military engagements in Afghanistan and Iraq, and the risk of conflict on Israel’s borders shifted the focus towards the manned military X-Hawk and unmanned Cormorant (formerly called the AirMule).

“Israel has some of the finest technical minds in the world, and Rafi knows the best of the best,” said longtime rotocraft industry engineer and customer advocate Jon Tatro, who worked on a joint Bell Helicopter-Urban risk reduction program on the X-Hawk in the mid-2000s. “He’s very good at getting what he needs and knows a lot of people.”

Urban Aeronautics’ defense unit, Tactical Robotics Ltd, hovered its one-ton AirMule UAV for the first time in late 2009 near Yavne at Richon LeZion airfield. Its renamed Cormorant UAV completed its first autonomous, untethered flight at Megiddo airfield in northern Israel on Dec. 30, 2015. The company has been expanding the flight envelope ever since.

The Cormorant is designed to fly a 1,100 lb (500 kg) payload on utility and cargo missions and also undertake lifesaving battlefield casualty evacuation missions. (The Cormorant is weight-restricted to this maximum payload to comply with the international Missile Technology Control Regime, MTCR, treaty, which also applies to drones.)

In April 2017, Metro Skyways Ltd, the manned aircraft unit of UrbanAero, announced plans to develop the five-seat CityHawk “flying car” over five years based on the Cormorant’s internal ducted fan system and chassis.

Designed for air taxi and aeromedical use, the CityHawk will initially be powered by a gas turbine engine, but will be designed from the outset to convert to liquid hydrogen and eventually to 10,000 psi (700 bar) compressed hydrogen or electric battery power once those options become commercially feasible.

Yoeli believes that the utility of a VTOL aircraft will only be fully realized when it has the ability to take off and land anywhere “and has the footprint of a car.” Both the military and civil unmanned internally ducted Fancraft produce far less noise than a helicopter, Yoeli said, backed up by Urban’s acoustic testing and analysis. While the Cormorant cannot autorotate, safety equipment will include triple-redundant control systems and a ballistic parachute in the event of complete loss of lift, such as engine failure.

A Visit to Urban Aeronautics

After climbing six flights of stairs in the industrial building in the Yavne technology park, the last thing you expect to see is a pair of prototype Cormorants parked in the middle of UrbanAero’s office floor, next to the engineering offices, conference room, electronics lab and coffee machine. UrbanAero has no plan to fly its Fancraft inside buildings, but it has designed the fly-by-wire (FBW) flight controls to allow the Cormorant and future CityHawk to hover against the side of a high-rise building during a first response mission.
Most of the cowlings on the olive drab Cormorant prototype were open at the time of the author’s visit in late November 2017. UrbanAero was installing a more powerful 985 shp (735 kW) Safran Arriel 2S2 engine in the airframe to replace the 730 shp (545 kW) Safran Arriel 1D1 used for the more than 200 test flights.

Down the road, UrbanAero plans to relocate the engine from the center to the side of the future CityHawk to create space for a passenger cabin in the middle of the aircraft and eventually accommodate a second engine to provide “Category A” single-engine performance (continued safe flight if an engine fails).

**Enabling VTOL Technologies**

The seasoned engineers at UrbanAero have spent 30 to 40 years in the aerospace business. They have designed and developed advanced military aircraft (e.g. Kfir and Lavi), certified business jets (e.g. Westwind, Astra and Galaxy), FBW flight control systems, and a wide range of combat-proven UAVs.

Sixty years ago, the original tandem internal rotor Piasecki AirGeep proved the concept was sound, but it didn’t achieve the high cruise speed and range the US Army desired and was limited to flights in calm wind conditions.

Most of UrbanAero’s engineering and aerodynamics work since 2003 has focused on developing the enabling technologies required to transform the AirGeep concept into a highly maneuverable, efficient and economical VTOL design, leveraging more than 50 years of technology improvements since Piasecki’s VZ-8.

To better understand the aerodynamics of twin internal ducted aircraft, Yoeli set development work in motion when he purchased two Hummingbird ducted fan flying platforms from his former company and combined the two together in a composite airframe he called the CityHawk technology demonstrator, which he personally flew in 2003. It was powered by eight Zanzottera two-stroke fuel injected engines providing a combined power output of 250 hp (185 kW).

UrbanAero’s engineers then developed and tested scale models of different aircraft configurations and control systems in wind tunnels at Technion–Israel Institute of Technology, Penn State and the University of Arizona, and refined the designs using their “Panda” flying scale models.

Building on the lessons learned from the original AirGeep, the high disk loading Fancraft’s three key enabling technologies are a vane control system, side duct louvered openings for high-speed flight, and fuselage lift at high speed.

The fly-by-wire control system creates pure rolling and/or yawing moments, as well as pure side forces, through the modulated movement of 50 vanes mounted at the inlet and exit of the each of the two fan ducts in the airframe. These 200 vanes on the aircraft can each produce about 20 lb (9 kg) of sideward force, and a total of 1,000 lb (450 kg) of force if they are all deflected in the same direction at the same time, while still providing roll and yaw control.

Additional louvers in the front face of the fore duct and rear of the aft duct can be opened to change the pattern of airflow through the ducts and fans during high-speed flight, significantly reducing the drag that was inherent in the original Piasecki design. The airframe is designed to accommodate two electric thrusters at the rear of the aircraft, but these have not been installed. Yoeli explained that they may not even be required, given the high speed the aircraft should achieve by inclining the fuselage. The shape of the two fan ducts also received significant aerodynamic design attention to increase the lift generated. The Cormorant test aircraft recently received its third generation of ducted fan blades.

“First generation rotors were two four-bladed variable pitch props from Vesta, Inc. of New Jersey, which primarily served the experimental and homebuilt market,” recalled Yoeli. “When Vesta closed its business, we acquired Vesta’s technology and began designing and making its composite rotors ourselves in Israel that met FAA FAR 35 (propeller) certification requirements.”

“The first set of new rotors featured a hub with six all-composite blades with optimized twist distribution to account for the induced velocity distribution in the ducts,” he continued. “Following three years of detailed CFD analysis, we designed our third generation of rotors with an even better twist distribution. This rotor uses the same hub design so it was relatively easy to retrofit the Cormorant with new blades.”

The entire power transmission system was also developed in-house, with the gearboxes assembled and tested by Urban using high quality spiral bevel and helical gears from KHK in Japan.
machined to size. “All the machining (shafts, splines, adapters etc.) is done in Israel. It took us a few years,” Yoeli explained, “but now we are also independent as far as prototype aerospace grade gearboxes are concerned.”

**Fly-By-Wire Controls**

“The fly-by-wire (FBW) flight control system (FCS) is our own design. Ely Erenthal, our Flight Control System Specialist group leader designed the FBW system on IAI’s Lavi fighter project, so we have all the know-how we require,” said Yoeli. “We’re using a high-end RTOS [Green Hill’s INTEGRITY real-time operating system] and Matlab-Simulink as the main design tool. The FCS computers are made by RADA Electronic Industries, an Israeli defense company.”

The FBW system manages the engine, vane, duct and fan pitch controls to provide the Cormorant with six degrees of freedom in flight and the ability to precisely fly down an alleyway or land in a footprint as small as a car.

Developing the control laws for the FBW system is ongoing as the flight envelope of the Cormorant expands.

The Cormorant is also equipped with an extensive navigation (inertial navigation system and GPS) and sensor (radar altimeter, laser altimeters and a stabilized electro optical sensor) suite required for challenging autonomous missions requiring high-speed low-level flight in all-weather and threat conditions.

**Chasing the Market**

Since its formation, UrbanAero has zigzagged between manned and unmanned VTOL concepts as new opportunities and funding sources appeared for the privately funded independent company.

The first concept was the civil X-Hawk for air taxi and air ambulance use.

With the outbreak of urban warfare in Afghanistan and Iraq in the early 2000s, UrbanAero teamed with Bell Helicopter to study the use of internally ducted Fancraft to insert and extract special forces units and combat troops from urban battlefields, with the research work supported by the US Office of Naval Research (ONR).

Then, when the Second Lebanon War erupted on Israel’s northern border in 2006, the Israel Defense Forces (IDF) Medical Corps took an active role supporting the development of autonomous VTOL aircraft for casualty evacuation in circumstances when helicopters can’t be used.

UrbanAero has also studied the use of Fancraft onboard naval vessels. The smaller footprint of a Fancraft means less space is required for operating and storage than for helicopters.

**Civil Applications**

Yoeli was excited to talk about the Fancraft’s civil applications — partially as a result of the explosion of interest in electric VTOL (eVTOL) air taxis — after many years focused exclusively on military applications.

“The biggest advantage of helicopters is their ability to take off and land vertically throughout their mission to pick up and deliver cargo (supplies), passengers and casualties,” noted Yoeli.

“Helicopters and eVTOLs rely on low disk loading which requires large (single or cumulative) rotor disk areas and/or exposed wings, both of which restrict mobility in complex terrain and urban environments and severely limit or completely eliminate potential takeoff and landing locations.” In addition, battery-powered eVTOLs suffer from limited useful payload and endurance, said Yoeli.

Yoeli believes that there will be is a growing opportunity to provide air taxi services within major urban centers and the five-seat CityHawk will have a distinct commercial advantage over eVTOL concepts that are focused on one- and two-seat designs.

Sound measurements indicate that the Cormorant is quieter than conventional helicopters, and this community advantage will further improve when the propeller tip speed is reduced from Mach 0.7 to about Mach 0.5 by adding a second stage of blades to the ducted fan.

With a physical footprint one-fourth the size of a helicopter, the five-seat CityHawk has more places to land and can achieve more hourly movements than a larger helicopter. The smaller footprint also means that rooftops too small to accommodate a helicopter can now be developed for exclusive use as Fancraft vertiports. That’s a tangible benefit in huge congested city like São Paulo, Brazil, where 400 helicopters are used to fly executives to work every day, resulting in some helipads operating at capacity during certain times of the day. High utilization — flying more flights with more passengers — is always the key to making money in the commercial aviation business.

The CityHawk is being developed to take off and land in winds up 40 mph (65 km/h) and the fan blades heated to fly into known icing conditions. The opportunity to fly more revenue hours per year is a definite advantage since it means fixed operating costs can be amortized over a greater number of flight hours. It’s also
attractive to executives who regularly fly to work and don’t want to be stuck in the office overnight because of poor flying weather.

UrbanAero also believes the VTOL’s small footprint and inclement weather versatility will make the CityHawk attractive as for charter work, as well as to deliver emergency police, fire and ambulance services. The company also has plans for a much larger Fancraft, the 12-passenger Falcon XP.

Civil Certification
Yoeli feels that all manned eVTOLs that are intended for commercial service will need to be certified by the European Aviation Safety Agency (EASA) and the US Federal Aviation Administration (FAA) to the same exacting standards as any other commercial passenger aircraft.

“This sounds like a very reasonable approach and it is unimaginable to us that the FAA will think otherwise,” said Yoeli. “While this has many implications when it comes to the design and commercial prospects of current VTOL aircraft, it poses two very serious and immediate consequences for new eVTOL aircraft that utilize today’s battery technology.”

“The first one is a requirement for a pilot on board at all times — we haven’t even gotten to the point where “self-driving” cars are permitted to travel without a safety driver,” explained Yoeli. “The second is to always carry a 20-minute reserve in [visual flight rules] conditions and 30-minute reserve in [instrument flight rules] conditions.”

With the current battery technology providing 300 Watt-hr/kg capacity, Yoeli calculated that eVTOL aircraft operating today have a maximum endurance of just 20–30 minutes with one or two seats occupied and no reserves.

UrbanAero’s approach is to develop its new Fancraft aircraft using jet fuel engines — which provide 20 times more energy per weight than the current battery technology — and then incorporate anticipated improvement in batteries, motors, generators, power conditioners, avionics and structures at the time when they achieve maturity and commercial viability.

“Even in the unlikely event that batteries fail to make the expected technology leap in the next 5–8 years, hydrogen is always available as an alternative fuel with 60 times the power density of current electric batteries,” said Yoeli. “Hydrogen can be oxidized either via fuel cells, which is the best choice (fuel cells are also developing today at a tremendous pace), or alternatively, fed into a standard turboshaft engine that can be easily adapted to operation on hydrogen.”

“Using an existing, FAA-approved turboshaft engine can for example be an interim step until fuel cells are certified by the FAA and EASA for use as primary power plants in commercially certified man-carrying aircraft,” said Yoeli, closing with a quote from futurist Ray Kurzweil: “an invention has to make sense in the world in which it is finished, not the world in which it is started.”

Find out more about UrbanAero’s Fancraft at www.evtol.news, including more photos and a video.

About the Author
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From Hummingbird to Cormorant

As a conscript, a young Rafi Yoeli served in the Israeli Air Force (IAF) as an air traffic controller, studied aeronautical engineering at Tel Aviv University and joined Israeli Aerospace Industries (IAI) in the late 1970s when it was improving the IAI 1124 Westwind business jet, designing the 1125 Astra business jet and state-of-the-art Lavi jet fighter, and developing the Scout UAV for the IDF.

He then paused in his industry career to earn a Master of Science degree in aeronautical engineering and doctorate in artificial intelligence from Technion–Israel Institute of Technology in Haifa.

Upon graduating, Yoeli founded Aero Design & Development (AD&D) in 1987 to provide consulting aeronautical engineering services to defense agencies and aerospace companies.

Some of AD&D’s notable projects included the development of advanced flight control computers and software; development of the “Skylark” Mini-UAV (sold by Elbit to 20 nations); design of the Stingray unmanned maritime vessel; design and development of three different air-breathing jet powered UAV’s; and modification of an IAF MD500 helicopter to an unmanned role.

As an IAF reservist, Yoeli also spent several days each month for almost 30 years managing the maintenance and battle damage repair of F-16, F-15 and F-4 fighter jets, as well as AH-1F, MD500 and CH-53 helicopters.

Yoeli obtained his fixed-wing pilot license in 1980 and his helicopter pilot license in 1995, and soon began flying from home to his office in a Rotorway Exec helicopter.

At about the same time, Yoeli became intrigued with early internal ducted rotorcraft such as the Hiller VZ-1 Pawnee one-man flying platform. (See “Walking on Air: Individual Flying Platforms of the Past, Present … and Future?” Vertiflite, Spring 2004.)

In 1997, Yoeli designed, built and flew AD&D’s Hummingbird ducted fan flying platform kit, which was powered by four Hirth piston engines. Yoeli placed a small advertisement for Hummingbird kit aircraft in the Experimental Aircraft Association’s Sport Aviation magazine for the kit.

“I got more than 1,500 responses from the advertisement from people who wanted to buy the kit. But because the Hummingbird was designed to remain airborne after losing any one of its four single cylinder engines, when all engines where running it had a lot of extra power,” said Yoeli. “I decided not to sell the kit because I was concerned that irresponsible people would open up the throttle, climbing up rapidly and then getting hurt or worse.”

Using major components from the Hummingbird, AD&D developed the Hornet UAV, which was first flown in early 2000. The design was optimized to fly a large payload above the duct that could provide 360-degree coverage.

Yoeli’s interests then shifted to internally ducted tandem fan aircraft as represented by the Piasecki VZ-8Z and VZ-8P(B) AirGeeps developed with US Army funding in the late 1950s. (See “Driving on Air: 20th Century Flying Carpets,” Vertiflite Spring 2005.)

To explore the tandem fan concept, Yoeli bought two Hummingbird kits from AD&D after he sold the company to Elbit Systems and joined them together to create a tandem ducted VTOL platform that he built and flew.

Yoeli flew the initial Fancraft technology testbed in October 2003, built from two Hummingbird fans. (UrbanAero photo)

To fly the Hummingbird, the standing pilot provided directional control by shifting his weight; but that wasn’t an option in the tandem duct design. “It was obvious that the pilot (me again) would need a new way to control the vehicle in roll,” recalled Yoeli.

“The vane control system we’re now using on the Cormorant Fancraft actually started out as a ‘poor man’s’ alternative to rotors with cyclic control, which I couldn’t afford. That’s how the patented vane control system was born and it was definitely these two Hummingbirds joined together that started it all.”

The AD&D Hummingbird, piloted by Yoeli, in 1997. (UrbanAero photo)