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STARTING SMALL, THINKING BIG

> ELECTRA DEMONSTRATES TURBOELECTRIC DISTRIBUTED PROPULSION
> INITIAL TARGET MARKET IS eSTOL REGIONAL AIR MOBILITY
> NASA BID EXTENDS TECHNOLOGIES TO 200-SEAT AIRLINER

ELECTRA.AERO PHOTOS

Electra's Islander chase plane (on the ground) represents the nine-passenger market the startup is targeting initially.

Graham Warwick Manassas and Warrenton, Virginia

At a sleepy airfield in rural Virginia, a bright yellow airplane leaps off the runway after an improbably short ground roll under the power of eight small electric propellers.

Electra.aero's EL-2 Goldfinch is the size of a Cessna 172, but the startup has big ambitions for the technologies this piloted aircraft has been built to demonstrate: turboelectric distributed propulsion and blown-lift ultra-short-takeoff-and-landing.

Even as it develops a nine-passenger electric short-takeoff-and-landing (eSTOL) aircraft for regional air mobility, cargo transport and military logistics, Electra is unveiling its concept for a 200-seat turboelectric airliner that could enter service in 2040, producing half the emissions of today's aircraft.

Electra founder and CEO John Langford points to a chart from the 2021 U.S. Aviation Climate Action Plan that shows sustainable aviation fuel (SAF) being by far the biggest contributor to achieving the goal of net-zero carbon emissions by 2050. A thin blue wedge is labeled "new aircraft tech."

"The U.S. Aviation Climate Action Plan is basically just SAF," he says. "The new aircraft technology share is pathetic. There is a lot more that needs to be done there, as SAF does not change the carbon coming out of the tailpipe."

Electra leads a team that has submitted a proposal to NASA for the Advanced Aircraft Concepts for Environmental Sustainability (AACES) program to study an airliner that could enter the market in the 2040s to help aviation meet its 2050 net-zero goals. Awards are expected in June, "but we are committed to this however that comes out," says Ben Marchionna, Electra director of technology and innovation.

Extrapolating technologies being pioneered on the EL-2, Electra has developed a concept for a hybrid-electric airliner that would consume half the fuel of an Airbus A320 or Boeing 737 on a typical 900-nm mission, with 30% lower operating cost, 90% less noise and 95% fewer contrails. The aircraft would fly on electric thrust only, powered by a turbogenerator running on SAF or hydrogen and batteries.

Electra is based at Manassas Regional Airport in Virginia. In the company's hangar at the time of Aviation Week's visit in late April were its two chase planes, both designs from the 1950s: a Helio Courier with the super-STOL performance for which the startup is aiming and a Britten-Norman BN-2 Islander representative of the nine-passenger market the startup is targeting.

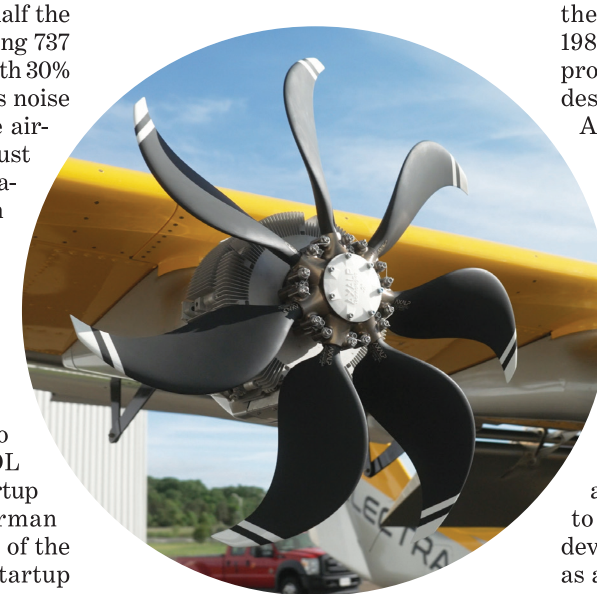
That day, the technology demonstrator, known as TD-2 internally, was a short flight away at Warrenton-Fauquier Airport, a quieter airfield where the company has more freedom to conduct its test flights, which consist mainly of progressively shorter takeoffs and landings.

Electra's objective with TD-2 is to demonstrate that distributed electric propulsion blown lift enables extreme STOL with takeoff-and-landing ground rolls of just 150 ft. At the time of Aviation Week's visit, the demonstrator, flown by test pilot Cody Allee, had achieved 150-ft. landing and 175-ft. takeoff distances (see page 58).

The demonstrator's 150-kW series-hybrid powertrain is built around a helicopter auxiliary power unit driving an existing gearbox and generator, all mounted Cessna 172-esque in the nose. The turbine is sized for cruise. Two liquid-cooled battery packs under the fuselage handle peak power and provide redundancy.

TD-2 made its all-electric first flight on Nov. 11, followed on Nov. 17 by its first hybrid-electric flight. The aircraft has surpassed 10 hr. of flight time on 17 flights, regularly flying for more than 1 hr., with its longest flight exceeding 1.5 hr. Its slowest speed achieved is 25 kt. and highest altitude 6,500 ft.

Flights have demonstrated turbogenerator shutdown and restart, different combinations of motor failure in flight and minimum controllable airspeed. The next phase of flights, for which TD-2 has been fitted with new propellers in its four outboard motors, will take the aircraft to 60-deg. deflection on the inboard double-slotted flaps in pursuit of the target 150-ft. takeoff ground roll.



New outboard propellers increase thrust and efficiency to improve takeoff acceleration, climb performance and stall suppression.

The original design was constrained by the need to use the same off-the-shelf 4,000-rpm motors on all eight propellers. The outboard propellers have been redesigned with scimitar-shaped blades to reduce noise and increase thrust by 30%, allowing even shorter takeoffs.

On TD-2, the four inboard propellers blow over the large flaps and generate most of the lift. The four outboard propellers blow over the ailerons, which droop 25 deg. This also generates lift but is mostly used for control. The arrangement is a result of modifying a Cessna 172 wing for the demonstrator, Electra says. The production aircraft will have full-span flaperons.

On approach, glidepath angle is controlled using inboard propeller thrust to modulate wing lift. Roll and yaw are controlled using outboard propeller thrust to augment the rudder at low airspeed. A second stage of TD-2 flight testing will develop flight control laws for precision landing, an essential capability for eSTOL in commercial operations.

Across the ramp from Electra at Manassas is Aurora Flight Sciences, the company Langford founded in 1989 and which built many one-off prototypes but never transitioned a design to production. Langford sold Aurora to Boeing in 2017 and stepped down as CEO in January 2020 to lead Electra, a startup he founded with a singular focus on bringing a nine-passenger eSTOL aircraft to market.

At Aurora, Langford worked with a team at the Massachusetts Institute of Technology (MIT) to build and fly a subscale model of a blown-lift eSTOL aircraft. MIT professors Mark Drela and John Hansman are now senior technical advisors to Electra. Chris Courtin, who led development of the subscale eSTOL as a graduate student at MIT, is the startup's chief engineer for the technology demonstrator.

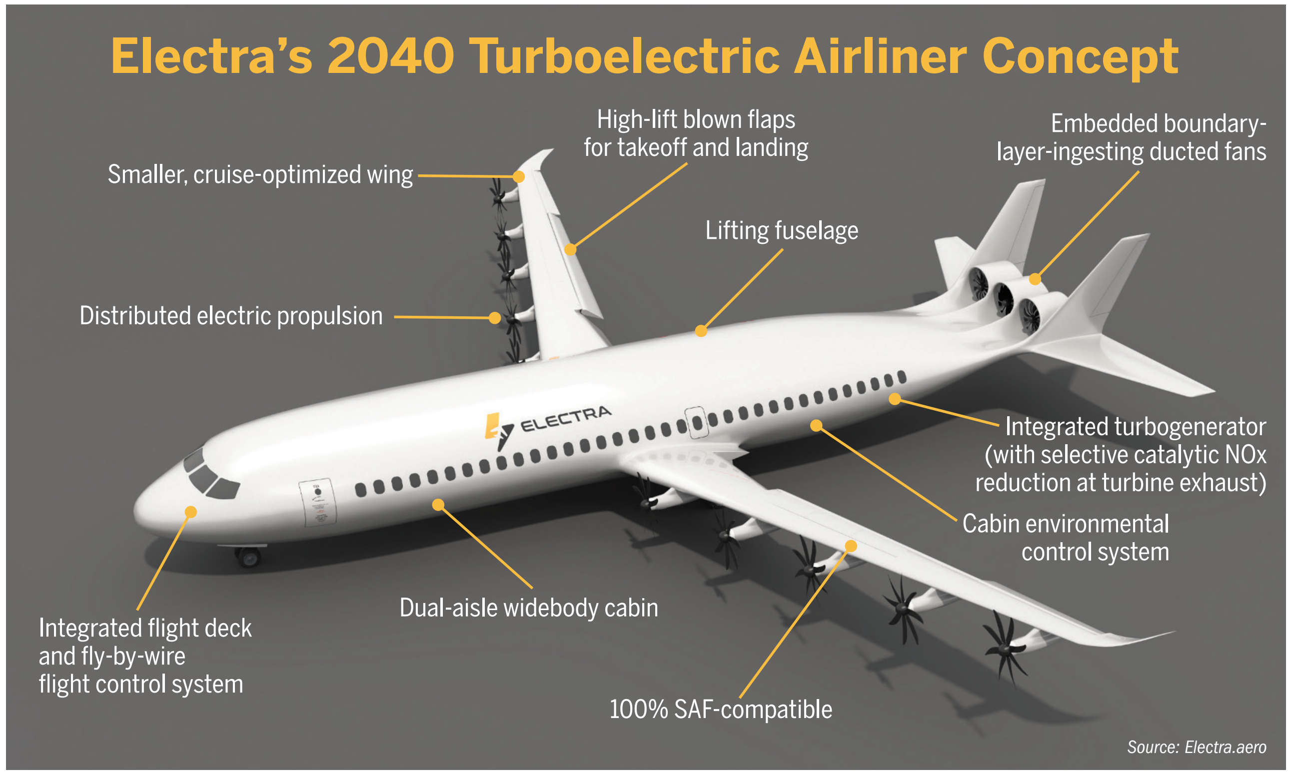
While at Aurora, Langford also worked with Drela and MIT research engineer Alejandra Uranga on development of the D8 concept for a quiet, fuel-efficient 2035-timeframe airliner under NASA's N+3 program. Uranga is now chief engineer for research and future concepts at Electra. Drela and Uranga's experience developing the D8 design clearly shows in Electra's 2040 airliner concept.

As has happened in the electric vehicle market, a debate over battery- versus hybrid-electric is raging in aviation. Langford and Electra are firmly in the hybrid camp. Electrification guru Mark Moore and his startup Whisper Aero back all-electric and also have submitted a proposal for NASA's AACES program. The Whisper Jetliner is a battery-powered, 100-seat regional airliner. Moore asserts that only all-electric propulsion offers a compelling operating cost advantage through lower energy and maintenance costs.

It was Aurora's experience with electrification that persuaded Langford that battery-electric aircraft were not ready for commercial aviation: trainers yes, urban air taxis maybe, but not airliners. "At first electrification looks attractive, but the more electric it gets, the worse the performance," he says. "The problem is battery weight."

Langford has a long connection to hybrids. He and Drela were part of the human-powered aircraft team at MIT that won the Kremer World Speed Competition. "The MIT Monarch B of 1984 was a human-battery hybrid aircraft," he says. The pilot, with an energy density of 6 Wh/kg, was assisted by 30-Wh/kg nickel-cadmium batteries.

While batteries are improving, Langford points to the slow progress in lithium-ion batteries certified for aircraft, from 80 Wh/kg in the Boeing 787 in 2011 to 170 Wh/kg in the Pipistrel Velis Electro in 2020. Batteries approaching 290 Wh/kg at the cell level—235 Wh/kg at the pack level—are expected to be certified in electric vertical-takeoff-and-landing (eVTOL) vehicles in 2025. That is still well below what is needed even for a short-range commercial aircraft.



Source: Electra.aero

The Advanced Research Projects Agency-Energy (ARPA-E), the U.S. Energy Department's equivalent to DARPA, has launched the Propel-1K program to develop 1,000-Wh/kg energy storage for aircraft, trains and ships. Electra has teamed with the University of Michigan (UMich), which has two projects under Propel-1K: Herald and Redox.

"We plan to demonstrate a 1,000-Wh/kg cell by mid-2025," UMich Associate Professor Venkat Viswanathan says. Propel-1K will build on a prior ARPA-E program, Scaleup, under which the university developed an aviation-ready battery module called the Kilostack, he says.

The Kilostack handles the mechanical, thermal and electrical aspects of the battery module and allows cells with different chemistries to be plugged in and swapped out. Under Scaleup, UMich has developed and tested a 450-Wh/kg lithium-metal cell, achieving an energy density of 330 Wh/kg at the module level.

This module underwent propeller-stand testing at eVTOL developer Pivotal (formerly Opener) in December; a flight test in Pivotal's Helix single-seat ultralight eVTOL is planned for the end of this year. "We are constrained to a few kilowatt hours, so we needed a small testbed," Viswanathan says.

Currently a 1-kWh module weighing 3 kg, the Kilostack provides the core element that will allow UMich to move forward with Propel-1K. "We can take that 1-kWh module and swap in a 1,000-Wh/kg Herald or Redox cell and get a system weighing 1 kg," Viswanathan says. UMich plans to have a lab-scale prototype, a single-layer cell, by July 2025 and to swap the Herald or Redox into the Kilostack module by 2027.

Even 1,000 Wh/kg is not enough to enable a midmarket commercial aircraft, Langford says. There is a big difference between the specific energy of a cell and a pack, he notes, with packaging factor, safety margins, cell aging and reserve energy leaving less than 30% of battery capacity available for flight.

"With 1,000 Wh/kg, you can get to a reduced-performance thin-haul regional," he says. "To go bigger, you have got to do something else. Hybrid-electric distributed electric propulsion is the something else for the next 50 years."

Electra's strategy is rooted in the belief that batteries will not be ready to power commercial aircraft for several decades and that, using those same batteries, hybrid eSTOL aircraft can perform similar missions to eVTOL vehicles with longer range and without the need for vertiports and charging infrastructure. The 200-seat concept signals the startup has ambitions for its technology beyond regional air mobility.

The company has formed a team to develop its concept for a 2040 turboelectric distributed-propulsion airliner. In addition to MIT and UMich, the team includes American Airlines and Lockheed Martin Skunk Works. As "customer equivalents," American provides the demand signal from airlines while Lockheed is looking at "dual-use" military applications of the commercial platform such as aerial refueling. Honeywell is working on the electrification system, integrated flight deck and fly-by-wire flight controls. "The turbogenerator would be an engine in their size class," notes Langford.

The team is engaged in aircraft concept exploration, looking at technology assumptions, scenario definition and infrastructure requirements. "Clean-sheet designs have no legacy," Uranga says. "We can look at technologies and where they make sense, and at what ranges and payloads make sense."

Beyond turboelectric power generation and distributed electric propulsion, Electra has identified technologies including a lifting fuselage with a dual-aisle cabin and embedded boundary-layer ingestion using electric ducted fans in the tail. A feature of MIT's earlier D8 concept, the double-bubble fuselage, provides about 80% of the benefit of a blended wing body at lower risk, she says.

"We can open up the design space," Uranga says. "For the D8, one option was to slow down to Mach 0.7." With the fuselage proving some of the lift, this enables a smaller, lower-sweep wing for about a 10% fuel saving and helps with the integration of boundary-layer ingestion and distributed electric propulsion, she says. Using the propellers to blow the wing flaps avoids the complexity and weight of a conventional high-lift system.

Boundary-layer ingestion—ingesting and reenergizing the slow-moving fuselage boundary layer to fill in the wake and reduce drag—promises up to 20% reduction in fuel burn, Uranga says, with 8-10% from improved aerodynamics and 8-10% coming from a lighter airframe with smaller engines. The potential benefit from boundary-layer ingestion is so large, she says, "it allows electrification to buy its way in."

Langford highlights another benefit. In the D8, boundary-layer ingestion involved embedding turbofans in the tail. This created the risk of an uncontained failure in one engine knocking out its neighbor. "On D8, we were never able to solve the fratricide problem with side-by-side engines," he says. "The Electra concept avoids that. Those are not engines at the back; they are boundary layer control fans. The turbogenerators are somewhere else."

"The total is greater than the sum of the parts," Uranga says. "We can open the design space and allow the system to optimize how it wants to, versus being constrained by a legacy approach." MIT pioneered this process with the D8 and developed a physics-based aircraft optimization modeling tool called Tasopt, or Transport Aircraft System OPTimization. Electra wants to take the approach a step further.

"What Tasopt did for the N+3 airframe, we want to extend to the turbogenerator," Langford says. "First-generation hybrid-electric with an existing turbine works, but it's only scratching the surface. In a clean-sheet design, we can optimize that." Using batteries for the main mission and fuel for the reserves changes the optimization and allows a higher level of electrification while meeting certification requirements.

For each level of battery performance there is a different optimum for the turbine, Langford says, noting that there has been little development work done on turbogenerators for aviation. "The turbogenerator will not look like today's turbines, which are optimized for propulsive efficiency," he says. "We can use technology from ground power generation like recuperation."

"We can add contrail control," Uranga says, pointing out that treating the exhaust to remove water vapor is practical for a turbogenerator. Batteries also could be used for propulsion in regions where contrails form and be recharged later by the turbogenerator. And MIT is developing a post-combustion catalytic converter to remove nitrogen oxides from the turbine exhaust. "It's not just about electrification; it's what it enables," she says.

Electra is flying its eSTOL technology demonstrator out of Warrenton-Fauquier Airport in Virginia.

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