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URBAN AIR MOBILITY

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URBAN AIR MOBILITY

Since Uber first articulated its vision for urban air mobility (UAM) in October 2016 in its seminal Elevate white paper, technical progress has been rapid. More than 10 electric vertical-takeoff-and-landing (eVTOL) prototypes are flying, and scores more are in development.

But technical progress is not enough to make UAM a reality. An unprecedented level of cooperation across an entire ecosystem of manufacturers, regulators, operators, financers, airspace services and infrastructure providers is required to enable this new market. And, ultimately, the public must accept and adopt this new mode of urban transportation.

Announcements have been coming thick and fast from vehicle manufacturers—some more plausible than others. Germany's Volocopter and China's Ehang are well advanced in flight tests of their multirotor eVTOLs. Astro Aerospace and SureFly are among others testing multicopter designs.

And it is not just startups that are in the running. Airbus is flying the single-seat tiltwing Vahana, and its four-seat ducted-rotor CityAirbus will follow soon. Boeing subsidiary Aurora Flight Sciences has flown its two-seat lift-plus-cruise Passenger Air Vehicle, and Kitty Hawk is testing its Cora, another lift-plus-cruise two-seater, in New Zealand and California.

Bell has unveiled its five-seat Nexus, with its six tilting ducted fans, and assembled a powerful industry team including Safran for the hybrid-electric propulsion system, EPS for batteries, Thales for flight controls, Moog for actuators and Garmin for avionics. All the major industry players are getting engaged in eVTOL and UAM.

Much work remains to be done. Regulations are taking shape within the FAA and the European Aviation Safety Agency. NASA is nearing completion of its Unmanned Traffic Management project to develop the underlying technology that will enable vehicles, from package-delivering drones to passenger-carrying air taxis, to fly safely at low altitudes over cities.

Uber still plans to begin experimental flights in test cities in 2020 and limited commercial service with certified vehicles in 2023, and the industry is studying the market in fine detail to understand who will fly, where and for how much. Cities around the world are engaging with vehicle developers, service providers and regulators to offer themselves as test markets.

Studies are generally positive, showing encouraging public acceptance for the urban air mobility concept—provided it is safe and quiet—and identifying cities, and specific routes within those cities, where UAM can potentially provide an attractive and affordable alternative to ground transport.

As they move toward the first experimental demonstrations and pathfinder certifications, the UAM market and eVTOL industry are approaching a pivotal point where the rubber hits the road—or rather, the rotors cut the air—and we will find out whether they can really can open up urban transportation to the third dimension of flight and rise above the gridlock.

Graham Warwick
Managing Editor, Technology
Aviation Week & Space Technology

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Uber Advances eVTOL Design With Common Reference Concepts

Graham Warwick

How do you create a new form of aviation? By collaborating, Uber contends. To realize its Elevate vision of urban air transport, the ride-hailing giant has assembled a phalanx of partners across the entire ecosystem from vehicles to vertiports.

Uber is also investing in internal teams to tackle what it sees as key gaps in industry's ability to build ride-sharing networks of electric vertical-takeoff-and-landing (eVTOL) air taxis within cities, including noise, batteries, airspace and infrastructure.

► Common reference models represent different eVTOL configurations

► Concepts will help industry weigh tradeoffs and validate designs

► Uber developing low-noise design tools to fill gaps challenging industry

At its second Elevate Summit in Los Angeles on May 8-9, Uber is assembling the entire urban air mobility (UAM) ecosystem and unveiling models and tools it is developing to help industry design new classes of aircraft with which it has no experience.

"Manufacturers know how to produce aircraft, but none have developed an eVTOL for urban air mobility," says Rob McDonald, Uber's head of vehicle engineering. "We look for gaps in technology, tools and testing and spend money to fill those gaps and share the results with our partners."

UBER TECHNOLOGIES

Uber's eCRM-003 is a distributed electric propulsion eVTOL concept with separate lift and cruise propulsion systems.

Uber's eCRM-003 is a distributed electric propulsion eVTOL concept with separate lift and cruise propulsion systems. Credit: Uber Technologies

Taking a leaf out of NASA's book, Uber is developing distributed-propulsion eVTOL common reference models (eCRM) that industry can use to develop and validate designs. The company is releasing its first eVTOL concepts to industry at the summit, with more to come.

The first, eCRM-001, has four sets of paired rotors for vertical lift and tilting wingtip propellers for vertical lift and forward thrust. Another concept, eCRM-003, has four sets of rotors for vertical flight and a tail-mounted propeller for cruise flight.

NASA uses the CRM to enable different teams to work on the same hard problem—the design of a high-lift system for commercial aircraft—and share their results. Uber sees five uses for its eCRMs, says former NASA engineer Mark Moore, director of aviation engineering.

"All these vehicles have complex flow problems, where propulsion, aerodynamics and control interact, and acoustic issues," he says. "This requires variable-fidelity toolsets that need to be validated and compared, similar to what

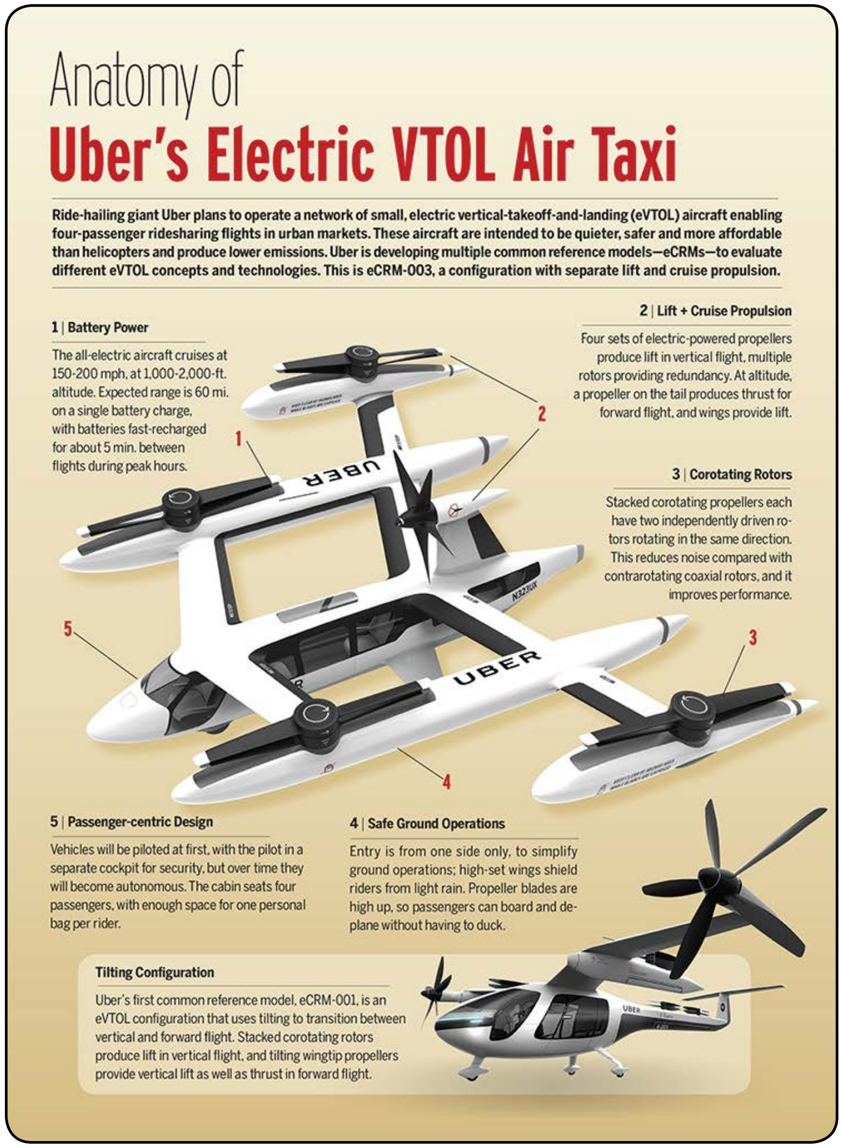
NASA does with the high-lift CRM."

Secondly, eCRMs act as reference concepts for trade studies as developers look across many different configurations. Uber's models also are intended to help socialize new ideas, "like concept cars that automotive manufacturers never intend to build but use to get ideas across to stakeholders," Moore says.

A fourth function is to validate that the requirements Uber has developed are correct. "We have developed an extensive requirement set, and the eCRMs help validate that the requirements are correct and show they are achievable," says Moore.

Fifth, the common reference models will advance eVTOL by allowing developers to understand if technologies buy their way onto different vehicle concepts. "It is not about any one vehicle," he says. "It is about understanding a bunch of vehicles that are so different."

The eCRMs will help industry make the tradeoffs between the complexity of articulation and the redundancy of distributed propulsion. "Those are the big questions in eVTOL, and we are making a tremendous effort in those two directions," says Moore.



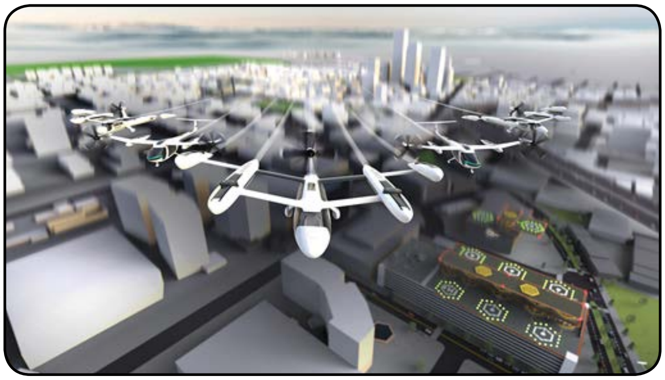
The eCRMs are being developed internally by Uber's vehicle team located in San Luis Obispo and San Francisco, California, to support its partners as they develop their vehicles. Partners onboard to date are Aurora Flight Sciences, Bell, Embraer and Pipstrel Aircraft. More partners will be announced at the summit.

The first eCRMs are representative of the broadest sets of eVTOL configurations with the potential to meet Uber's requirements: designs that use separate propulsion systems for lift and cruise and those that articulate—tilting wings, rotors or ducts—to transition between vertical and forward flight.

They are not entirely generic and feature technologies Uber intends to investigate with its partners. These include the stacked corotating rotor—a lift rotor with dual propellers that rotate in the same direction. This avoids the wake interference problem that makes contrarotating rotors loud, says Moore.

The blade pairs are not at 90 deg., but are spaced just 10 deg. apart. This has two beneficial effects. One is that the blade pairs act like a high-lift flap on a wing and increase performance. The second is that nonuniform blade spacing produces a different and quieter acoustic signature.

The two propellers in each pair are driven independently, which provides redundancy, and digital control allows precise management of the phase between the rotors to minimize noise, says McDonald.



UBER TECHNOLOGIES

Uber's Elevate vision is to operate networks of ride-shared four-passenger eVTOL air taxis within congested cities.

Uber also is investigating how to address gaps in the design tools available to its partners. This includes developing toolsets that enable acoustics to be brought into conceptual design. "Low noise is usually brought in late in the design process; it's one of the last things to be considered," McDonald says.

"The acoustic community has spent decades developing tools appropriate for late in the design process. They are high-fidelity and rigid and not suitable for the early, creative design process," he says.

Urban air mobility will be a nonstarter if the public decides the vehicles are too noisy. Uber does not believe the existing tools are sufficient to meet its aggressive noise goals—which essentially are to blend into the background noise around vertiports in a busy city.

"We are very focused on being able to design for ultra-low community noise. That is the differentiator [for eVTOLs over helicopters] in this market. And the industry has not done that before," Moore says. "So we've focused on developing low-fidelity tools that can be used up front in conceptual design."

These tools are dedicated to the design of the partners' vehicles, which cannot be shown, and the eCRMs are a way to showcase the results without giving away proprietary designs. This is part of Uber's strategy to share information as widely as possible to advance the art of eVTOL design across industry.

Already, M4 Aerospace Engineering has applied Uber's eCRMs to developing weight-prediction methods for some of the most unique features of eVTOLs. Georgia Tech has used these concepts to perform analyses to compare and contrast the safety of different concept approaches.

Uber and Empirical Systems Aerospace are developing a physics-based modeling and assessment tool to evaluate eVTOL performance and controllability during transition between hover and cruise. The tool will help Uber and partners better understand new configurations through static and dynamic vehicle flight modeling.

Most of Uber's effort involves taking existing design tools and streamlining and automating the connections between them so they can be used more easily in the early stages. This encompasses connecting vehicle geometry to unsteady aerodynamic modeling to acoustic propagation and post-processing tools that simulate how sounds are perceived by humans.

Uber is funding research on developing vortex particle code for unsteady aerodynamics and better metrics to measure the annoyance caused by vehicles that have acoustic signatures quite different to those of conventional helicopters.

NASA Rolls Out Urban Air Mobility 'Grand Challenge' Plan

Guy Norris

Widely viewed until recently as bordering on science fiction, the age of urban air mobility (UAM) is fast approaching reality and is poised to transform both aviation and society, says NASA. Now, with international activity in this new market accelerating, the agency has unveiled plans to cultivate the development of a U.S.-led urban air revolution.

Launching the UAM Grand Challenge plan in Seattle on Nov. 1, NASA Aeronautics Associate Administrator Jaiwon Shin said the advent of urban air vehicles "holds an enormous amount of promise, to a level not seen since the introduction of the jet engine, but we have to do this right." Noting the growing pace of UAM developments in Europe and Asia, he said, "If the U.S. doesn't develop scalable, profitable and safe operation, then somebody else is going to eat our lunch."

► Initial Grand Challenge GC-1 phase in 2020, with more complex GC-2 in 2021

► Early tests will evaluate UAM aircraft and systems through varying scenarios

Addressing an audience that included airspace, avionics and traffic management companies, as well as government agencies and representatives of 47 different vehicle developers, Shin stressed the need for a broad, consensus-based approach to producing a road map toward a viable UAM future. "This is not a NASA or FAA event; it's a community event," he said. "If we work together, these things could happen."

Unlike earlier Grand Challenges, however, the UAM plan does not include prize money. "This is the community learning together and trying to raise the water level together," says Shin. "Looking at these challenges, no one company or government entity will be able to overcome them all. It shouldn't be addressed by any one of them. I can't think of any other country that can do this first and get this right." However, he warns: "If we are not methodological and use best practices, this will become a total disaster. There are lots of system-level issues, and public perception is a big question mark."

Based partly on results of two NASA-funded UAM market studies that found "air metro" operations could be profitable by around 2028, with up to 750 million passenger trips in 15 metro areas possible by 2030, the agency believes the emerging sector could be a commercial game changer. This rosy forecast also applies to nonpassenger traffic. Studies by Crown Consulting and Booz Allen Hamilton also suggest that by 2030 "last-mile package" delivery could be profitable and result in 500 million deliveries annually.

"We are doing this to enable a real market," says Shin. "It's not a one-off stunt that would take another 15 years to scale up and become profitable and safe. We want that from the get-go. I'm very hopeful we are in a

NASA

NASA's Grand Challenge ultimate vision is to test aircraft and systems in a UAM scenario involving hundreds of simultaneous operations that will pave the way for a mature system with tens of thousands of flights under optimized, automated control.

good position as a country to do this. I get questions a lot from Congress and the White House about whether we are too late, and what we need to do. What we are doing here is what we do best. We have the government working with industry and the community to methodically and steadily put together the necessary capabilities for real."

The FAA also stresses that public acceptance and safety remain underlying requirements for a viable urban aviation industry. "UAM will not fly without it. Do not underestimate the need to work with local communities," says FAA unmanned aircraft systems (UAS) integration office executive director Earl Lawrence. Appealing to would-be participant developers to present their safety case rather than business case, he adds, "Safety is the key to get your business off the ground, literally."

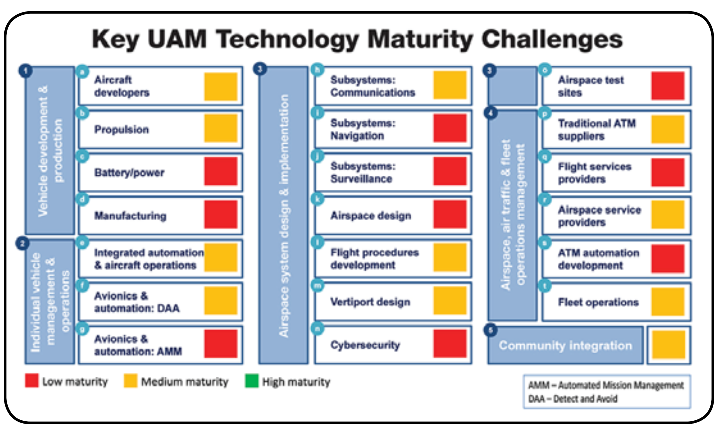
Overall, he says: "[The FAA] is committed to this dynamic shift and doing it in a way that continues the safety of our airspace system. We need to know what it will take to bring this technology to market and meet society's expectations for safety."

Advising the airframe and systems providers, Lawrence says, [the fundamental requirements for UAM] "won't be too different from those already established to fly an aircraft in the national airspace system today." He adds, "We are shifting from prescriptive compliance-based rules to performance-based regulations, and our focus is on what can already be done under the existing regulatory framework until we can update regulations where we need it.

"If you are looking for the formula, it is research plus operations in the real world. The research comes first, then operations in a real environment and in volume. Then we will know how to update regulations," Lawrence says.

Under the Grand Challenge plan, aircraft and system developers have until Nov. 16 to respond to NASA's request for information, says Davis Hackenberg, UAM strategic advisor for NASA's aeronautics research mission directorate. Based on initial feedback, the agency expects to hold webinars early next year to set up working groups and, shortly afterward, plans to draft a series of Space Act Agreements (SAA) with initial participants that will identify baseline airworthiness and qualification requirements.

By the end of 2019, SAA participants are due to begin a series of qualification scenarios that will be used to prove the basic capability of their vehicle designs to meet safe operations as well as to begin NASA's airworthiness process. This must be completed prior to flying in Grand Challenge 1 (GC-1), which is the first of an anticipated series of tests in various scenarios aimed at paving the way for foundational UAM vehicle design readiness and operational robustness.



NASA's initial state-of-the-art assessment for technology maturity levels needed for an intermediate, passenger-carrying intrametro air shuttle.

GC-1 is due to start in January 2020, with a more sophisticated GC-2 planned for the same period in 2021. NASA, which will provide access to a UAM test range to be set up at Armstrong Flight Research Center in California, says the second series of challenges is expected to address "key safety and integration barriers across the UAM ecosystem while also emphasizing critical operational challenges." The agency also has outlined additional GC-3 and GC-4 phases, which will add further levels of maturity to the UAM system through scenarios that increase in number, complexity, technology and operational readiness, standards and regulatory emphasis.

To provide a basic framework for the initiative, NASA has developed six UAM reference missions, three nonpassenger-carrying and three passenger-carrying. These range from initial technology-state missions such as public safety vehicles and medical transport to intermediate-state tasks such as small package deliveries and intrametro air

shuttles. Then, in a mature state, these progress to the most sophisticated reference missions including UAS multi-package delivery and ubiquitous intrametro taxi services.

During the formation of the reference missions, "we stumbled on something we got excited about," says Hackenberg. "For each of them, we have defined what is the required UAM maturity level [UML]," he adds, referring to the creation of a series of notional steps toward large-scale, fully developed urban air mobility systems with tens of thousands of simultaneous operations. The initial state, which will be addressed in the early GC phases, will focus on UML-1 and UML-2. The first step toward maturity will involve early operational exploration and demonstrations of a small number of aircraft in limited environments, while UML-2 will add low-density and-complexity commercial operations with some assistance from automation.

The testing of intermediate state-level maturity will focus on UML-3 and -4, the former covering low-density, medium-complexity operations in an urban area with closely spaced landing areas and automation for scalable, weather-tolerant operations. The move to the next level, UML-4, will evaluate medium-density and -complexity operations with collaborative and responsible automated systems. These and later tests are expected to be undertaken on other ranges across the country.

"Our sweet spot is UML-4. You are talking about 100 vehicles or so, and it covers trip distance, the turnaround time of vehicles and time to recharge batteries," says Hackenberg. With hundreds of simultaneous operations, a 100-strong fleet would have capacity to transport 5,000-10,000 passengers per day. "That's good, because when you get 200-300 vehicles, you start to get closer to 60,000 passengers. That's around 10% of the Washington metro system, and that starts to be significant. So that's where we focused our Grand Challenge," he adds.

The overall time line runs largely in parallel with much of the baseline development schedule already outlined by Uber for its Uber Air UAM plan. However, Shin says there is no specific area of overlap and hints that NASA, which is already partnered with Uber on modeling and simulation of the UAM environment, may be exploring additional cooperation with the ride-hail company. NASA believes the initiative also will provide a more sustainable platform for growth than the isolated demonstrations planned in cities such as Dubai and Tokyo. "I'm pretty sure they will succeed, but is that going to be scalable. That's the question," he adds.

Spotlight On Urban Air Mobility

Graham Warwick

Urban air mobility—manned and unmanned—has become the hottest area of innovation in aviation. Whether it will mature into a market or fizzle out depends on how successful manufacturers, operators and regulators are in tackling a wide range of technical, operational and societal challenges.

AIRBUS A3

EHANG

Propulsion

There is a divide between the likes of Uber, which wants all-electric UAM and believes battery technology will be ready to power small eVTOLs on short flights by 2023, and companies that believe hybrid-electric propulsion is a better near-term option and offers the range to operate more than just short intra-city hops. Much will depend on whether higher-energy-density batteries with new chemistries emerge as promised, although they initially are likely to have high costs and short lives.

KITTY HAWK

AIRBUS A3

Configuration

There is no dominant configuration yet in UAM, with eVTOLs divided into two broad categories: wingless and winged. Wingless eVTOLs essentially are scaled-up multicopter drones. They are not aerodynamically efficient in cruise and are best suited to short flights at low speeds. Winged eVTOLs transition from rotorborne vertical to wingborne horizontal flight. They are more efficient-—with higher speed and range—but more complex, requiring lift and cruise motors or tilting wings, rotors or ducts.

Safety

Urban air mobility is commercial air transport, but the safety level of general aviation—fixed- or rotary-wing—is not adequate for thousands of low-altitude flights a day over cities. Airliner-level safety is required. Some eVTOLs cannot autorotate like helicopters or glide like airplanes if power fails. Risks may be mitigated by the increased redundancy possible with electric propulsion or by ballistic parachutes that can deploy at extremely low altitudes and speeds, but safety will be a key design driver.

Certification

Many eVTOLs have some features that have not been certified before. Some have many. Such features range from distributed electric propulsion to automated flight control. The plan is to certify these vehicles using industry standards still in development. The European Aviation Safety Agency issued proposed airworthiness standards for eVTOLs for comment in October 2018. The FAA plans to issue special conditions for certification as it works toward a new airworthiness category for these vehicles.

SEE ALSO

► Rotorcraft Industry Enjoys Strong Demand for Military Helicopters

► Engine Prospects Dominated By Commercial Ramp-Up, Military Tech Push

Noise

Public acceptance is arguably the key concern with UAM: Are eVTOLs safe enough for people to fly on them, and are they quiet enough to avoid creating annoyance? Both issues cause the use of helicopters to be held back in cities. Electric motors are intrinsically quiet. Distributed propulsion reduces rotor-tip speeds, and ducts shield noise, but propulsion-airframe interactions can generate noise.

VOLOCOPTER

Airspace

If the most optimistic forecasts for UAM are realized, there could be more flights per day over one city than the entire U.S. today, in airspace outside the established air traffic management system. The intent is to extend the unmanned traffic management, or UTM, construct being developed to manage low-altitude drone operations to enable UAM, with airspace services provided by commercial entities.

UBER

Manufacturing

To fulfill the vision of high-density urban operations, eVTOLs will have to be built at high volumes and low costs with which the aviation industry has no experience—5,000-10,000 a year versus 100-500 for aircraft today. Manufacturers are looking to the automotive sector and the automated high-rate assembly of carbon-fiber vehicles such as BMW's i3, but the performance required, and resulting complexity, makes it challenging to automate the manufacture of aircraft structures.

TERRAFUGIA

LILIUM

Infrastructure

Urban air taxi services will begin using existing heliports, but higher-density operations will require new infrastructure. Initially, this could mean reactivating idle rooftop helipads or repurposing the upper levels of parking structures. But ultimately, dedicated high-throughput vertiports will be required, purpose-designed to process passengers, recharge vehicles and connect to other modes of transport.

Financing

There are more than 100 known eVTOL projects. The majority are startups. Only a handful will survive. In 2017, Lilium secured $90 million and Volocopter $30 million, including backing by Daimler and Intel. In 2018, Joby Aviation raised $100 million from investors including Toyota, JetBlue Airways and Intel. Google cofounder Larry Page is bankrolling Kitty Hawk's Flyer and Cora eVTOLs. Investment is flowing into the nascent sector, but much more will be needed to move from flying models to producing vehicles.

Bell's Nexus Air Taxi Concept Rings Changes For eVTOL Market

Graham Warwick

A year after teasing the fledgling electric vertical-takeoff-and-landing (eVTOL) industry with a mockup of a futuristic air taxi cabin, rotary-wing giant Bell has unveiled the first major configuration details of its Nexus on-demand urban air mobility (UAM) concept.

Revealed at the Consumer Technology Association's CES 2019 show in Las Vegas, Bell's Nexus is distinguished by six tilting ducted fans and sized to carry four passengers and a pilot. Powered by a hybrid-electric propulsion system incorporating batteries and an unspecified Safran turbine engine, the Nexus is designed to "safely and efficiently redefine air travel," says Bell's executive vice president for technology and innovation, Michael Thacker.

► Bell Nexus targeted at mid-2020 service entry

► Initial vehicles will be capable of fully autonomous operation

► Six hybrid electrically powered tilting ducted fans integrated with flight control system

As one of five companies teamed with Uber to develop urban air taxi demonstration vehicles for trials in Dallas and Los Angeles as early as 2020, Bell is also unveiling the Nexus as part of a broader strategy aimed at applications beyond air taxis, including logistics and military missions. While the idea of air taxis is not new, Thacker says: "What is new is the emergence of technologies that enable quiet, safe, efficient, affordable urban air mobility operations at scale using small, heavily automated electric and hybrid-electric vertical lift aircraft."

With its six ducted fans tilted forward in airplane mode, Bell expects the Nexus to cruise at around 130 kt (150 mph).

BELL CONCEPTS

The Nexus is a preliminary product of four integrated frameworks used by Bell to help define a UAM model. "Using operational, regulatory, manufacturing and technology frameworks, we are enabling innovative technology, charting a path toward regulatory support, and ultimately informing aircraft design and operating requirements," says Thacker.

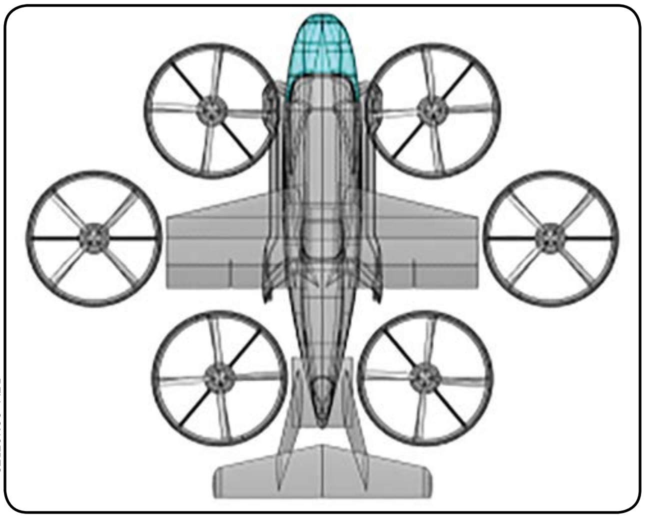
"While we are not sharing specifics on active projects today, we believe that viable commercial operations are possible in the mid-2020s," he says. "Tomorrow's challenges facing our population centers are not going away and will not be solved by conventional means. There is a lot of work to be done to create a viable UAM network, but we believe the future is real and possible and coming soon to a city near you."

The Nexus is a "pretty serious aircraft," says Bell Vice President of Innovation Scott Drennan. "[The design is] what we believe is a certifiable vehicle that makes this market real in the future. Hybrid propulsion reflects our belief in a broader capability set. The ducts are great for noise and enable a new set of folks to approach this aircraft comfortably.

We want this to reach everyday folks who have to commute to work, visit families and get from Point A to Point B."

Sized to fit within a 37 X 37-ft. light helicopter landing site, the Nexus is targeted at a range of 150 mi. and a cruise speed of around 130 kt. Bell is aiming for a takeoff gross weight of 6,000 lb. and maximum payload capacity of 800-1,000 lb.

The cabin's automobile-styled interior is configured with side-by-side seating for four, plus a forward single seat for a pilot. "We think that is where the market is. We think a pilot will be there initially, to help people accept the technology, but we think the pilot will eventually go away and be replaced by an autonomous system," says Drennan. "In this ecosystem, you will find people who are bullish and some who are bearish. We are in—we are believers, and we are going to make this become real in the marketplace."



BELL CONCEPTS

Forward and aft fans are mounted close to the fuselage; the midfan set is mounted on the tips of the stub wing.

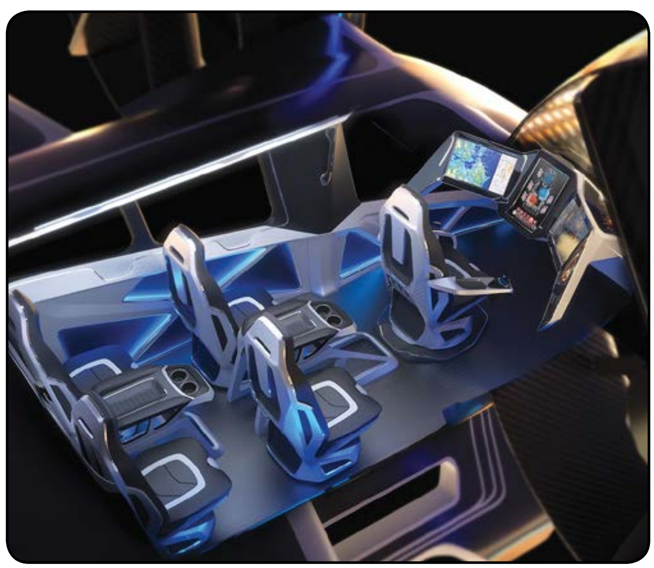
Bell's confidence stems in part from its extensive heritage in ducted-fan and tiltrotor designs going back to the XV-3 of the 1950s and, more particularly, the X-22 short-take-off-and-vertical-landing X-plane of the 1960s. Adopting a configuration very similar to that of the much larger X-22, the Nexus features high-mounted ducted fans arranged in pairs.

The forward and aft fans are located on pivoting struts close to the fuselage, and the midset is attached at the tips of a centrally mounted stub wing. The single-rotor fans, each consisting of four blades and measuring 8 ft. in diameter, are housed on hubs supported within the duct by guide vanes. In helicopter mode, the ducts are tilted horizontally to generate vertical thrust, and in aircraft mode they tilt vertically to provide forward thrust. The ducts are passive lift systems and generate the vast majority of lift in airplane mode, along with the wings in the center," Drennan says. The duct shape generates lift regardless of what is spinning inside of it in airplane mode."

A Safran turbine engine is housed on the upper aft fuselage and, along with batteries, provides energy for the vehicle's hybrid-electric propulsion system. The engine exhaust is ducted aft between the twin vertical stabilizers of the aircraft's Pi tail.

A hybrid-electric propulsion system was adopted for greater mission flexibility, says Kyle Heironimous, propulsion lead engineer for Nexus. "That does not mean we've closed the door on future technologies," he notes, "so we are always keeping our eyes on the status of batteries, fuel cells and future energy storage, and a lot of technologies that we are developing for hybrid systems including electrical machines, motors, generators and power electronics."

As well as providing the turbine engine, Safran will be responsible for development of the series hybrid-electric propulsion system and drive system. The company, which began



BELL

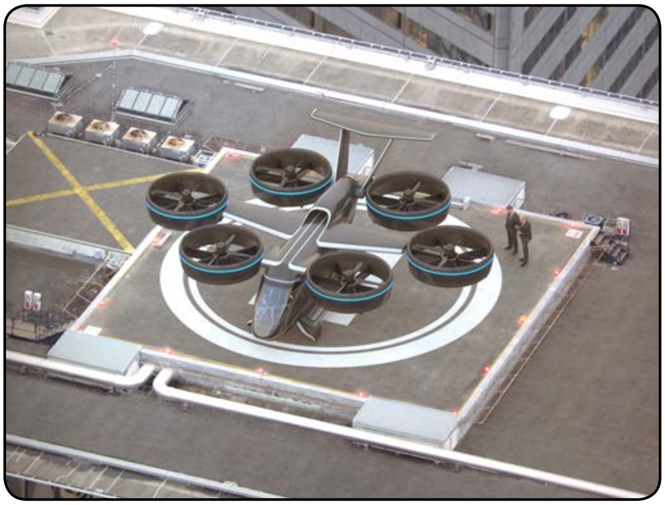
Beginning at CES Bell is surveying public reaction to advanced single and two-inceptor pilot control designs for the Nexus as alternatives to conventional helicopter controls.

ground runs of a 100-kW hybrid-electric distributed propulsion system in mid-2018 at its Pau-Pyrenees test site in France, also recently unveiled the first of a newly developed family of electric motors up to 500 kW, and is providing a modified version of its Ardiden 3 turboshaft to provide electrical power on the Boeing-backed Zunum 12-seater ZA10 hybrid-powered aircraft.

In the Nexus the turbine-driven generator will produce DC electricity, which will be transferred to motors in each duct via a redundant power distribution network. "In addition to the turbine or turbo-gen as we call it, we have a high-power, high-energy battery energy storage system that provides a redundant and dissimilar source of power to the propulsion system," Heironimous says.

The architecture enables the battery to assist the generator's electrical output "when the aircraft needs it during transition or maneuvers," he says. "Also, if in the unlikely event that the engine shuts down in flight, the batteries have enough power to land the aircraft safely or potentially continue its mission and land safely. That means we don't have to carry extra parachutes and can always land safely under our own power."

Power from the generator and battery combine into the distribution system that feeds the six fans, each of which contains a direct-drive electric motor. "That is important because it is attached directly to the rotor system," says Heironimous. "There is no intermediate gearbox or lube system. We are keeping it as simple as possible, and that keeps it reliable, cost-effective and safer."


BELL

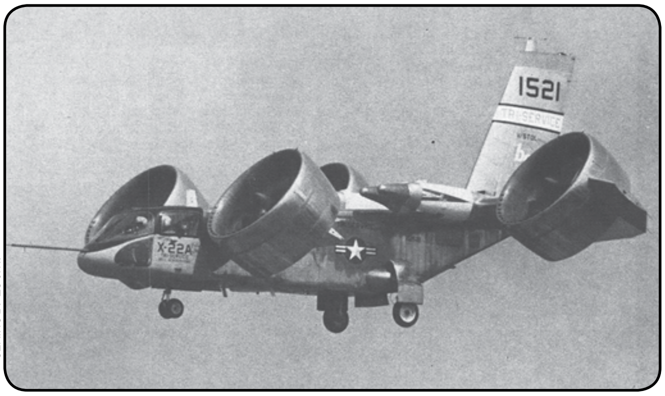
The Nexus is designed to fit into a 37 X 37-ft. size area typical of a light helicopter landing site and smaller than the 45-ft. box size allowed by Uber.

Logan, Utah-based Electric Power Systems (EPS), which led development of the lithium-ion battery pack for NASA's X-57 Maxwell electric propulsion demonstrator, will provide the energy storage system, including batteries, power electronics, thermal management and battery management. "Batteries are always a trade between high power with low energy or high energy with low power," says Heironimous. "But a VTOL mission needs both, which means it is a heavy battery. Only within the past couple of years have we reached the point where batteries are reaching the energy and power densities necessary to enable electric and hybrid eVTOL."

The advanced EPS battery system makes the hybrid approach feasible and enabled Bell to optimize the size of the generator and turbine. "Using the battery to shave off the peak power demands of the mission allows us to size a smaller turbine, which is more efficient and lighter," says Heironimous.

The Nexus will have a Thales-developed fly-by-wire flight control system (FCS) that will be "different to anything Bell has done before in many ways," says flight controls lead engineer Jeff Epp. The flight control system will be distributed, with centralized flight control computers connecting to remote electronics and motor controllers. For the first time on a Bell aircraft, primary flight control surfaces will be moved by all-electric actuators rather than conventional hydraulic systems. The electromechanical actuators and motor controllers will be provided by Moog.

"For the first time, we have integrated the FCS with the propulsion system," says Epp. Flight control computers will control the motors, rotors and ducts. "The flight control computers control those motors to not only provide thrust but also to use those rotors to dynamically control the aircraft," he adds. "That allows us to do roll, pitch and yaw control as well as use them for hover mode and forward flight." In helicopter mode roll, pitch and yaw control is provided by varying rotational speed on the fans and directing thrust using movable vanes in the fan ducts. In airplane mode, flight control is provided by rudders on the canted vertical tails and ailerons on the midfan duct struts.



AW&ST ARCHIVES

The Nexus takes clear advantage of Bell's ducted fan design heritage, including the successful X-22 STVOL X-plane tested in the 1960s.

The flight control system will also work closely with the autonomous vehicle management computer (VMC), which will be developed by Garmin. The VMC is "the brain of the aircraft," says Nexus avionics lead Frankie Mazzei. For power management, the VMC will take information from the battery and relay it to the engine, while for navigation it will be able to take ground station commands and relay those to the FCS. "Today, that is all managed by the pilot," says Mazzei. "The goal of the VMC at Bell is to be the ultimate pilot assistant, enhance situational awareness, reduce workload and increase safety. The end goal is to be fully autonomous."

Bell is reluctant to detail the development schedule, but Drennan says the program is currently "somewhere between preliminary and critical design reviews." Entry into service is targeted at the mid-2020s, with demonstrators and prototypes "phased in between now and then," he says, adding that the first vehicles will be fully autonomous to "unlock speed in the schedule" and enable the early potential for an optionally piloted aircraft. The route to certification is undecided but "could come out of Part 23," Drennan says.

Airbus Survey Shows Public Support For UAM—But Safety, Noise Are Key

Graham Warwick

Safety and noise are the public's biggest concerns about urban air mobility (UAM), but initial acceptance of the concept is surprisingly high, concludes a public perception survey conducted by Airbus.

The survey, done in Los Angeles, Mexico City, New Zealand and Switzerland, shows 44.5% of all respondents support UAM while 41.4% believe it will be safe. The survey shows communities are most concerned by safety to people on the ground (55.6%), followed by the type and volume of sound (49.3% and 48.8%, respectively) generated by electric vertical-takeoff-and-landing (eVTOL) vehicles.

The initial perception study was conducted by Airbus UTM, the former Altiscope unmanned traffic management project under Airbus' Silicon Valley outpost A3 that now reports to the European manufacturer's recently formed UAM unit. The survey is part of efforts to ensure responsible deployment of the new technology, says Jessie Mooberry, head of deployment at Airbus UTM.

"What the survey told me, which I expected, is we need to do a lot more work here. This is a baseline study. We identified pain points and validated that people are concerned about them," she says. "We have our work cut out for us now, but what I learned is people are really excited about this technology. One out of two people are excited about this, keen to use it, and that's a surprise. I was expecting it to be closer to 15-20%—your early-adopter type, but it's much higher. We are at a good starting point."

The survey involved 385 paid respondents in each of the four geographies. Los Angeles was chosen because of its congestion and pollution and high number of helipads, which gives it potential for early deployment of UAM. Mexico City has similar traffic problems and a history of adopting new mobility technologies: Airbus' Voom on-demand helicopter service is now operating in the city.

► Support for UAM from 44.5% of survey respondents

► Likelihood of using air taxis varies between regions

► Results may support UAM service during rush hours

New Zealand has expressed interest in UAM as a way to provide intercity transport to promote tourism while preserving its natural landscape, says Airbus UTM, and Switzerland cites similar increases in tourism and intercity travel, as well as a more open regulatory framework compared with the U.S.

Survey respondents were briefed on the technology and then asked psychographic questions to understand what types of lifestyles have strong views on UAM. Scenario-based questions elicited their reactions to different types of air-taxi operations and specific concerns about the time of day, frequency and altitude of flights, the sound and visibility of aircraft, types of passengers being flown and landing location.

In terms of positive perception, the best-case scenario is an aircraft that sounds like a bee buzzing, flies at high altitude once an hour, early in the morning, carrying four diverse passengers and landing far away from the respon-

AIRBUS

Public perception study shows surprisingly high level of early support for urban air mobility, says Airbus.

dent's home. The worst case is an aircraft that sounds like a helicopter, flies at low altitude 100 times an hour, at night, carrying a family of two and landing near to home.

Overall, 56% of respondents were concerned about safety to people on the ground. The next group of concerns, all at 48-49%, were type and volume (number of flights) of noise, and the time of day and altitude at which the aircraft are flying. Of lower concern were duration of noise (46%) and whether the aircraft was visible (45%). The parameter that generated the lowest concern was landing location (41%).

Generally, initial reactions are most positive as altitude increases, frequency of flights (sound) decreases, and time of day is earlier, says the study. This supports use of UAM during commuter rush hours. Higher altitude and lower flight frequency are also perceived as contributing to greater safety.

Respondent income and age are factors as well. In L.A., 50% of those earning more than $150,000 a year had positive reactions to UAM, but only 39% of those earning less than $60,000 did. Across all geographies, 55% of people aged 25-34 viewed UAM positively, but only 15% of those 75-84 years old did so.

While overall support for UAM was positive, the likelihood of using air taxis varies significantly between the four locations. In Mexico City, 67% of respondents are likely or very likely to use UAM, and only 8% are very unlikely. In Los Angeles, the proportions are 46% and 21%, respectively.

It is a closer call in the other two regions. In Switzerland, 32% of respondents are likely or very likely to use UAM, and 29% are very unlikely. In New Zealand, the proportions are 27% and 28%, respectively. Congestion and commuting are much less important factors in these two locations, Mooberry notes.

Underlining this, the survey showed 25% of all urban residents were very likely to use UAM and 15% very unlikely, while 32% of rural residents were very unlikely to use UAM and only 16% likely. "This indicates that rural residents are more skeptical of using UAM," the study concludes. Respondents with long commutes and those who ride-share or use public transport are more likely to use UAM.

Mooberry says data from the survey is being shared with the vehicle, infrastructure and business-to-business teams within Airbus UAM. The study confirms the public is sensitive to vehicle noise, but the location of vertiports is less of a concern. The data is also being shared with regulators and city planners.

"The public may initially be more supportive of operations flown over the least-populated areas, such as waterways or open fields," the study concludes. "Also, established aircraft manufacturers with excellent safety records may be preferred to new market entrants."

The study also has a message for companies, such as Uber, that plan UAM demonstration flights with experimental eVTOLs over cities as early as 2020: Don't fly too frequently, and don't make too much noise or you might prematurely harden public opinion.

"Given that the frequency of flight presently causes concern, it will be important in early controlled field trials that greater frequency does not lead to a reduction in safety or a palpable increase in noise annoyance," the study cautions.

Mooberry says Airbus UTM plans to conduct further studies to investigate issues identified by regulators and planners, after specific events such as an autonomous car crash to see how that influences public perception of UAM, and in cities where Voom has been operating, to see if that increases acceptance.

The perception survey is among the first of its kind to apply a "peace engineering" approach to socially responsible technology deployment developed at Stanford University, Mooberry says. This recognizes that social media has empowered citizens to influence the perception and adoption of new technologies.

Uber Boosted By FAA's Openness To 'Skylane' UAM Routing Concept

Guy Norris

Amid a flurry of emerging new electric vertical-takeoff-and-landing (eVTOL) designs, ride-sharing company Uber says its plans to reveal the international city selected for trials of its urban air mobility (UAM) system in June are on track, as is its intention to acquire an initial fleet of test vehicles in 2020.

As a sign of continuing progress, Uber also says the FAA is being "amazing" in its progressive stance to supporting the development of dedicated "skylanes" or airspace tunnels. These will form a vital element of Uber Elevate's aggressive push to develop aerial ride-sharing "at scale" in which networks of hundreds of vehicles carrying hundreds of thousands of passengers per day will operate between dedicated "skyports."

► Jaunt proposes eVTOL Carter slowed-rotor compound version for Uber role

► 140 eVTOL concepts now under study, test and development

Recognized as perhaps the most challenging aspect of Elevate, an innovative air traffic management system is seen as key to achieving the traffic densities necessary to make the UAM concept a success.

To find solutions, Uber is working with the FAA and NASA; it signed a second Space Act Agreement with the latter in 2018. Under the arrangement, NASA is using its airspace management modeling and simulation tools to assess the impact of small aircraft—from delivery drones to eVTOLs—in urban airspace.

The company's core investment "relates to the network management and airspace," says Mark Moore, director of engineering for vehicle systems at Uber Elevate. "We are a network management and software company, and this is a software problem. Instead of trying to do vehicles, which is outside Uber's experience, the company is focusing its investment on what they can do best, and helping the collaborative ecosystem spool-up, whether that is developing infrastructure or aircraft."

Speaking at the Vertical Flight Society's eVTOL symposium in Mesa, Arizona, Moore says "dynamic skylane networks are at the core of this [strategy]." Describing them as "tubes that go mostly through Class B airspace," the airway concept will "permit us to have high throughout through them with closely monitored flights from both a centralized and distributed perspective so they can be sequenced.

"From the beginning we said we would be flying visual flight rules and not instrument flight rules, because it is simply too burdensome to apply these to networks. What's cool is it looks like there is significant movement from the FAA to actually embrace these tubes without rule change, and for us to start moving toward autonomous flight rules—which is where we need to get to in the future," says Moore. "It's amazing what the FAA is

CORGAN

The FAA is working with Uber on dynamic "skylane" routes that would connect to skyports built in existing areas of high noise background, such as freeways.

currently doing and I appreciate how much they have been able to adapt."

The drive to agree on the basic rules governing the development of the low-level (500-1,500-ft.) air routes over urban areas is pivotal to Uber's UAM vision. "The tubes I'm talking about are en route and, although they will be static to begin with, they're called dynamic for a reason," says Moore. The concept includes the ability to alter the track of busy flight routes to reflect changing travel needs, traffic demand, and prevention of eVTOL noise being focused on a specific neighborhood.

Initial operations will be tested first in Dallas and Los Angeles as well as an international city, the identity of which will be announced in June. The list of potential host nations includes Australia, Brazil, India, France and Japan. "We will start doing experimental flights with partner vehicle companies to prove out safety and noise characteristics and, in 2020, with those experimental flights we will be able to make commitments to lease or buy a significant quantity of vehicles," says Moore.

Uber is working with vehicle partners Bell, Boeing subsidiary Aurora Flight Sciences, Embraer, Karem Aircraft and Pipistrel Aircraft. "Each is completely different, and proof that we are in the equivalent of a Wright Brothers era," says Moore.

The initial lease/purchase deals "will justify our partners going into the $300-500 million certification phase, and we plan to start commercial operations with the first 50 aircraft across these cities by the end of 2023," he says. "We are very serious about that forcing function. We understand it is a great challenge to get these aircraft certified by that date, but we believe that the forcing function is a powerful influence to drive technological as well as regulatory change."

Ultimately, "when we are able to implement autonomy, that's when the real magic happens," says Moore. When all five seats initially configured for a pilot and four passengers are occupied by fare-paying travelers, Uber says the results could be dramatic. "If we can hit less than 50 cents/per passenger mile, then we become competitive with private car ownership, and it is clear from our economic analysis that there is a path to get there. We are very excited about making that happen as soon as possible."

JAUNT AIR MOBILITY

Jaunt Air Mobility is proposing an Uber-compliant eVTOL based on Carter Aviation Technologies' slowed-rotor compound (SR/C) concept.

A potential new addition to the Uber lineup was also announced at the symposium by startup Jaunt Air Mobility, which has acquired the rights to Carter Aviation Technologies' slowed-rotor compound (SR/C) concept. Jaunt founder and entrepreneur Kaydon Stanzione says flight tests of a new Uber-compliant eVTOL compound vehicle based on a modified version of the Carter vehicle could occur this year.

The SR/C is a combination of autogyro and compound helicopter with, in the case of the eVTOL version, a powered rotor for vertical lift and, for forward flight, four scimitar-shaped propellers mounted on a wing. The rotor is slowed in flight to reduce drag and allow higher speed than a conventional helicopter. As lift is shared with the wing, the

rotor has a low disc loading, and because it rotates at only around one-third the speed of a conventional blade set, has a lower tip speed.

The Jaunt entry is among the latest of 140 eVTOL designs now in some form of initial study, test or development. Commenting on the "crazy" number of concepts at the eVTOL symposium, which was itself oversold with a record 360 attendees, Vertical Flight Society President Mike Hirschberg says: "The hype keeps increasing, but what we should be afraid of is something like the dot-com boom and bust. That was catastrophic and wiped out whole companies, but 5-10 years later we got the incredible benefit of all this infrastructure laid out, and new technologies that really transformed society."

Hirschberg adds that the mushrooming eVTOL business is currently climbing a steep slope toward "a peak of inflated expectations," which will likely be followed by a trough of disillusionment. With the field of competitors narrowed, there would then follow a "slope of enlightenment" leading to a "plateau of productivity." The industry, he says, "wants to reduce the peak and smooth that transition as much as possible and get to this eVTOL revolution, which I really think will transform society over the next 10-20 years."

One eVTOL developer widely considered a front-runner for the broader UAM market is Joby Aviation, which now says its S4 five-seat eVTOL air taxi will be capable of 200 mph and operate at noise levels 100 times quieter than a helicopter. Disclosing new performance characteristics at the symposium after flying both subscale and full-scale demonstrator vehicles in California, Joby says testing is progressing well as it launches into the preproduction development and certification phase.

XTI Aircraft was one of the few designers of hybrid-powered VTOL concepts to update recent progress at the symposium. The company is preparing to begin flight tests of its 65%-scale proof-of-concept TriFan 600 ducted-fan VTOL business aircraft "in coming weeks." With a revised tail, winglets and more widely spaced lift fans, the company is targeting certification in 2023.

The TriFan 600 will have a 1,000-shp turboshaft engine driving three generators that power dual 250-kW motors on each of two 6-ft.-dia. wing-mounted ducted, pivoting fans and a counter-rotating, 5-ft.-dia. fan mounted in the aft fuselage. The two larger fans are mounted on the wing leading edges and tilt between vertical and forward flight. The smaller lift-only fan, which helps counter adverse yaw through a set of vanes, is shut down and covered over with doors in forward flight. A battery pack will generate 250 kW to boost the fans in vertical-takeoff mode.

Sikorsky Demos Autonomy As Key To Its Urban Air Vision

Graham Warwick

Sikorsky is declaring its interest in urban air mobility (UAM) but stopping well short of unveiling a vehicle designed specifically for the nascent market. Technologies it has been developing for the past decade are maturing to support urban air taxis, but the issue that must be tackled first, the company believes, is developing the infrastructure to provide a travel experience the public will embrace.

Adoption is a key challenge facing UAM and, in addition to showcasing technologies it thinks are key to enabling safe and efficient urban air transport, Sikorsky is presenting its vision of the passenger experience at the Helicopter Association International's Heli-Expo show in Atlanta on March 5-7. In parallel, the company provided Aviation Week with unique insight into the technology behind the vision.

Sikorsky likens its envisioned travel experience to a three-dimensional elevator, with the passenger simply pushing a button to select their destination and a multimodal transport network deciding how best to get them there. To flesh out its vision, the Lockheed Martin-owned helicopter manufacturer is working with former United Technologies sister company Otis Elevator and Richard Branson's The Spaceship Co., manufacturer of Virgin Galactic's suborbital-tourism SpaceShipTwo.

► Autonomy, intelligence and infrastructure are central to the company's vision for UAM

► Development is focused on the interface between human and autonomy

► Optionally piloted UH-60 Black Hawk is expected to fly this spring

A decade ago, Sikorsky launched a research plan focused on three areas it saw as fundamental to the future of vertical lift: speed, autonomy and intelligence. The speed initiative has resulted in the S-97 Raider and Sikorsky Boeing SB-1 Defiant demonstrators. The intelligence pillar is producing advanced analytical tools now being used to improve support for its S-76 and S-92 commercial helicopters.

The Matrix Technologies autonomy program is developing certifiable capabilities that Sikorsky plans to introduce incrementally across its commercial and military product lines. Along with advanced analytics and electric propulsion for future vertical-takeoff-and-landing (VTOL) vehicles, the company sees autonomy as foundational to enabling safe, reliable and affordable urban air mobility on a large scale.

SEE ALSO
► Matrix Technology Headlines S-92 Upgrade Plans

The autonomy effort is reaching a crucial stage, as Sikorsky works with potential customers on how to begin deploying the capabilities being developed. The technology is being used in an optionally piloted UH-60A Black Hawk testbed that is expected to fly this spring, while the U.S. Army is installing the Matrix kit in a UH-60M for flight testing this year.

The technology has matured to the point where the company is allowing people other than its test pilots—including this non-pilot Aviation Week editor—to fly its Matrix testbed, the S-76 Sikorsky Autonomy Research Aircraft (SARA). The current development effort with SARA is focused on refining the human-machine interface (HMI) that enables pilots and other operators to interact with Matrix.

SIKORSKY

An S-76B modified to fly-by-wire control, SARA is Sikorsky's testbed for the Matrix autonomy system.

"So far, only experienced pilots have interacted with the autonomy. But the level of maturity and HMI now enables us to put inexperienced people on board," says Chris Van Buiten, vice president of the Sikorsky Innovations research organization. Matrix enables the 12,000-lb. SARA to be flown, by pilots and non-pilots, via a tablet computer or control inceptors after little more than 30 min. of training.

"The intent always was to have people on board the aircraft operate it in a fundamentally different way and to move beyond sticks and pedals," he says. In a UAM vehicle, Matrix would enable a passenger to push a button and fly fixed routes between fixed locations. In other vertical-lift applications, autonomy could enable a helicopter to be operated with two, one or even zero crew, depending on the mission.

Matrix is focused on safety and on reducing controlled flight into terrain and crew-related issues that account for three-quarters of helicopter accidents. "Rule No. 1 is not to hit stuff," says Igor Cherepinsky, chief engineer for autonomy programs. But in addition to preventing the vehicle from colliding with obstacles, the autonomy system reduces workload on the crew throughout a mission.

"We give them more tools to be more successful," says Van Buiten. "We shift the burden of flying the aircraft onto the machine and let them think about the full context of the mission." On a demanding emergency medical mission, for example, the autonomy will fly the aircraft while the crew determines the best place to land next to the ambulance or which hospital to head to, he says.

"If we earn the right to go to single pilot it will be very valuable," he says, because of the growing helicopter pilot shortage. Van Buiten also sees "a real opportunity for performance" with autonomy. A single pilot would allow an additional passenger to be carried, and the accuracy and repeatability with which autonomy performs procedures would increase payloads on Category A takeoffs.

"Autonomy fundamentally changes safety, reduces cost, increases flexibility and enhances performance," says Van Buiten. Autonomy is also key to making the interface with urban air mobility "as simple as an elevator." The passenger will not have to decide the vehicle's route or altitude, but "just hit the button that says Rockefeller Center."

For Sikorsky, autonomy is also a key to enabling its vision of UAM "at the right level of safety," he says. At scale, air taxis around the world could be logging 150 million flight hours a year. At the accident rate now achieved by the S-92, around one per 1 million flight hours, that would mean an unacceptably high 150 accidents a year. "We need to be 100 times safer than the S-92," says Van Buiten.

SIKORSKY

A non-pilot Aviation Week editor prepares to put Sikorsky's autonomy system to the test.

The ability of the autonomy system to perceive and react to the world around it is essential to improving safety. At the core of Matrix is a world model built from digital terrain and obstacle databases. This is updated in real time with data from lidar and camera sensors. As the system plans and executes flight trajectories, it is always aware of any potential hazards and will not permit the helicopter to fly into an obstacle, even in response to a pilot command.

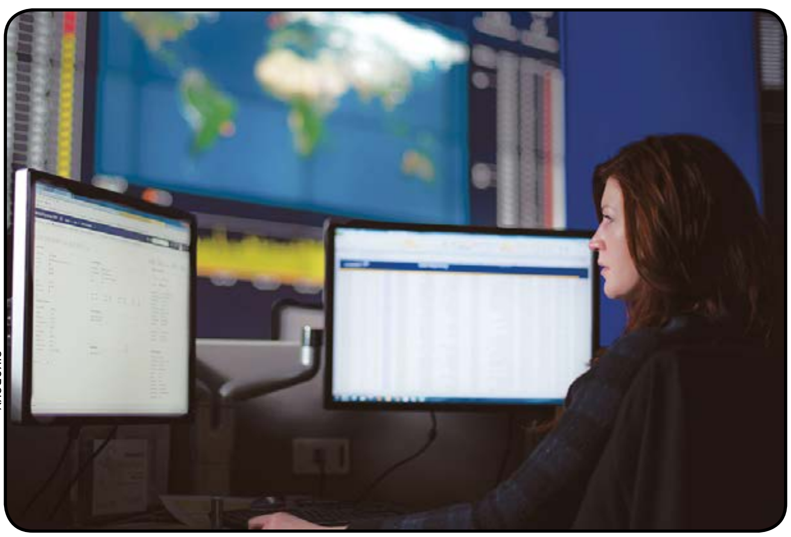
The S-76 SARA is a flying laboratory. The helicopter has been converted to an optionally piloted vehicle (OPV) by installing a fly-by-wire system with servos and clutches that drive the existing mechanical flight controls in response to commands from the Matrix autonomy management system. A safety pilot is always on board and can disengage the OPV system if needed to take back mechanical control.

The servos, triple digital flight-control computers and triple GPS/inertial navigation units, sensor pre-processors, a compact supercomputer and other equipment are mounted in the cabin. In the cockpit, the pilot in the right seat has a knee-mounted tablet as well as left and right control inceptors. The safety pilot in the left seat has a door-mounted tablet and conventional controls but does not have the inceptors.

Aviation Week was invited in late February to fly the SARA. The flight with Mark Ward, chief pilot for Sikorsky's Stratford, Connecticut, flight-test center, was preceded by a short training session in a simple simulator inside the modified recreational vehicle that is the Matrix ground control station.

Matrix is a research project, and the user interface is a work in progress, says Cherepinsky, but Sikorsky has reached the stage where it is working with commercial and military customers to evolve interfaces specific to how they operate. "The whole point is reduction in workload and moving from piloting to mission management by taking care of the things that take up the pilot's bandwidth," he says.

The autonomy system is normally controlled via the touch-screen tablet. Its display shows an image of the area around the helicopter. This can be two- or three-dimensional, and during flight it continuously shows terrain close to the aircraft and potential landing zones detected by the lidar system.



SIKORSKY

Advanced analytics used to support the S-76 and S-92 are among keys to Sikorsky's UAM vision.

Tapping a "Fly To" icon on the screen brings up three connected circles. Using these "super Mickey Mouse ears," the operator can enter an airspeed, altitude and heading and move cross-hairs over the map image to set a location. These become fly-to goals for the autonomy system.

Set an altitude and heading, tap "Execute," and SARA will lift off autonomously and come to the hover pointing in the desired direction. Enter a sequence of goals to define a flight plan, and the autonomy system will create and execute a trajectory that avoids known hazards, replanning on the fly if the three lidars constantly scanning a volume around the helicopter detect any obstacle not in the database.

For our flight, the autonomous takeoff to hover was loaded by the ground station, demonstrating the ability of the Matrix system to accept inputs from anyone on the network. This can be the pilot, copilot, a loadmaster in the rear cabin or someone on the ground guiding the helicopter to pick up a load. Once in the hover, Ward asked me to maneuver the helicopter over the airfield using the inceptors.

The second mode of interacting with Matrix, these controls mimic the functions of the conventional helicopter cyclic stick, collective lever and anti-torque pedals, but work in a fundamentally different way. Instead of pilot commands being sent directly to the fly-by-wire computers, they go to the autonomy system, where they become voting inputs to the motion-planning algorithms.

The inceptors give the pilot the ability to change the planned trajectory, perhaps to deviate from the planned flight to look at something of interest, but they do it through the autonomy system, so the modified flightpath always

avoids obstacles and keeps the aircraft safe. Release the inceptor, and the helicopter will safely return to the trajectory required to meet its original goals.

The right-hand inceptor is a small sidestick. In the hover, moving it side to side commands SARA to translate left or right; fore and aft makes the helicopter move forward or backward. In forward flight, sideways movement commands a banked turn; fore-aft increases or decreases speed.

The left-hand inceptor is a throttle-like grip: Pull back, and the helicopter climbs; push forward, and it descends. On the right edge of the grip is a thumbwheel: In the hover, this is rotated forward to turn left and backward to turn right. In forward flight, it is disabled.

With SARA in a stable hover, I played with the 3D-printed inceptors and quickly found I could easily move the helicopter around the airfield, looking only at a small display showing the target and actual groundspeed, altitude and heading to achieve the task.

After I repositioned us into wind, Ward asked the ground station to construct a departure flight plan. This would take us north along a river. Once the plan was uploaded, I hit "Execute" on the tablet, and SARA accelerated into a climb away from the airfield.

A modified S-76B, SARA has only partial fly-by-wire, and its safety system puts tight limits on the servo rates. As we repositioned over the airfield and again as we climbed out, gusts pushed the rates past the limits and the OPV system disengaged, Ward briefly taking back control before reengaging the servos. The optionally piloted Black Hawk is fully fly-by-wire and more robust, Ward says.

But the unexpected disengagements did show two things: that the system is safe and the transition between OPV and manual control is smooth, something on which the team has had to work, Ward says.

The Matrix system generates an idealized flight trajectory that the real helicopter strives to follow. This allows development of an autonomy system that is agnostic to the platform, Cherepinsky says, allowing the same algorithms to be used with different types of aircraft.

This was apparent during the preflight simulation training, where the helicopter's flightpath could be seen to be following as closely as possible a "rabbit" that moved along the ribbon in space representing the ideal trajectory generated by the Matrix system.

Under DARPA's Alias program, Sikorsky demonstrated the technology could fly both the rotary-wing S-76 SARA and fixed-wing Cessna Caravan, Ward simply carrying his tablet between the two Matrix-equipped aircraft. The system is being transitioned to the UH-60 under Phase 3 of Alias.

After the autonomy system had taken us north of the airfield to about 2,500 ft. at 80 kt., Ward told me to select and circle a landmark using the inceptors. Orbiting a point on the ground is normally a relatively high-workload piloting task, he says, but SARA's control system made it surprisingly easy. There was no apparent concern that I would exceed any of the S-76's limits in my ignorance as I increased bank angle to tighten the circle, the autonomy system keeping the aircraft safe.

An approach flight plan was then uploaded and executed, and we headed back to the airfield. It was still gusty, and Ward was poised on the controls in case of an OPV disengagement, but SARA successfully held to the inbound path following the river, then executed a surprisingly smooth and precise approach to the hover, then a gentle landing, all autonomously.

Sikorsky's original "2-1-0" crew concept for autonomy will be achieved with the two optionally piloted Black Hawks in the graduation demonstration under Alias. "Two crew will fly highly augmented, then one will get off, and finally the last crewmember will get out and turn the switch to 0," says Van Buiten.

"In parallel, we are working on commercial certification. It will be 'crawl, walk, run,'" he says. "Day 1 will not be a zero-pilot S-92 with 19 people on board. But there will be a lot of functionality in there that we will turn on as we earn the right to with regulators and operators."

Rigorously certified, high-integrity autonomy software is one key to Sikorsky's UAM vision. Another is the simplicity and redundancy of electric propulsion. Sikorsky built an electric helicopter demonstrator, the Firefly, in 2010-11, but it never flew because available batteries enabled only a short flight time. But the company set "tripwires on how industry would have to develop to get us interested again," says Jonathan Hartman, disruptive technologies lead for Sikorsky Innovations.

A third piece of Sikorsky's vision is the artificial-intelligence-driven prognostic maintenance capability the company is developing and fielding to support the S-76 and S-92. By applying advanced analytics to data downloaded from aircraft, Sikorsky's Customer Care Center in Trumbull, Connecticut, has gained approval to extend the lives of some parts based on how they are being used. The ultimate goal is to manage parts based on a "health bar," not a life limit, and an advanced health and usage monitoring system will be part of the Matrix offering. It also will be a key to safe, high-utilization UAM operations.

For now, Sikorsky's UAM vision features the S-76, already being used for urban on-demand service in New York. "The long-term vision of thousands of vehicles will need to see a change in aircraft. But the UAM mission is happening today, and we need to find ways to expand it," says Hartman. "It is easy to look at this as a technological challenge, but it is fundamentally about adoption. Until we crack that code, all these [electric VTOL] development programs could be academic exercises."