

News & Highlights

Electric Air Taxis Create Megadeal Buzz

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Big investments and partnership announcements made 2021 a landmark year for the nascent electric vertical take-off and landing (eVTOL) aircraft industry. Indeed, several eVTOL developers have the bold—and many say wildly optimistic—ambition to achieve regulatory certification and commence carrying paying passengers as early as 2024.

Four prominent eVTOL aircraft manufacturers separately went public in 2021, raising billions of dollars in total, through mergers with special purpose acquisition companies (SPACs) [1]. These were California, USA-based Archer Aviation (Palo Alto) and Joby Aviation (Santa Cruz); Vertical Aerospace, based in Bristol, UK; and Lilium Air Mobility, based in Munich, Germany.

Major airlines have also formed alliances with eVTOL manufacturers. In February 2021, United Airlines announced plans to work with Archer on the development of its aircraft and said it would acquire up to 200 of them once they are operational and meet certain requirements [2]. In June 2021, American Airlines announced a 25 million USD investment in Vertical Aerospace, and a pre-order of up to 250 aircraft—a potential commitment of 1 billion USD—if specific milestones are met [3]. The company further claims its pre-order book has reached 1350 aircraft with an estimated value of 5.4 billion USD [4]. Lilium announced a potentially 1 billion USD deal with Brazilian airline Azul in August 2021 [5], while Joby announced a partnership with the Japanese airline All Nippon Airways (ANA) in February 2022 [6].

In addition, in January 2022, Boeing announced a further 450 million USD investment in Wisk Aero, based in Mountain View, CA, USA [7]. A joint venture between Boeing and Kitty Hawk Corporation (Palo Alto, CA, USA), Wisk is one of the few eVTOL players—in addition to EHang of Guangzhou, Guangdong Province, China [8]—to have chosen to produce a pilotless, automated air taxi.

Generally small-winged aircraft that take off and land like a helicopter, eVTOL have more and smaller rotors powered by multiple electric motors in an effort to reduce weight. Once airborne, some or all those rotors tilt forward into a more energy-efficient, airplane-like cruise mode in which the aircraft's wings provide a larger proportion of the lift. Developers plan to use them to ferry commuters between towns and airports, moving quickly around urban areas or between neighbouring cities, or to transport cargo.

The list of new deals and corporate alliances is large, but then so is the potential market for these vehicles and the ground infrastructure needed to support them [9]. The investment bank

Morgan Stanley predicts the urban air mobility market such aircraft will create to be worth 1 trillion USD by 2040, and 9 trillion USD by 2050 [10]. Besides the financial interest, electric aircraft appeal to an aviation industry seeking to reduce emissions that make significant contributions to global climate change [11].

Driven by these factors, the sheer number of different eVTOL designs appearing across the world is unprecedented. The World eVTOL Aircraft Directory [12], maintained by the Vertical Flight Society (VFS, formerly the American Helicopter Society) based in Fairfax, VA, USA, topped more than 600 designs in January 2022, with nearly 200 new designs added in 2021 alone. “It is probably the most exciting time in aeronautics since World War II and the creation of the jet engine,” said Pat Anderson, professor of aerospace engineering and director of the Eagle Flight Research Center at Embry-Riddle Aeronautical University in Daytona Beach, FL, USA. “This is just like the golden age of barnstorming.”

The range of designs in development shows remarkable variation. For example, Archer's 80%-scale two-seater demonstrator aircraft (Fig. 1), called Maker, has 12 horizontal rotors, spaced across the front and rear of the wing, with the front rotors able to tilt forwards, becoming propellers after transitioning to forward flight. The company plans to start volume manufacturing their production aircraft, a piloted four-seater, in 2023 [13]. The Lilium Jet, by contrast, has 36 ducted electric fans, 12 distributed across canards at the front of the craft, and 24 distributed across the wings (Fig. 2) [14], though the company's next iteration of the aircraft will have a total of 30 slightly more powerful units [15]. The areas housing the fans rotate, enabling a vertical take-off and the transition into forward thrust.

Battery technology has advanced to a level—thanks in part to the electric car industry—where these aircraft are feasible, but with severely limited payload and range, said Anubhav Datta, associate professor at A. James Clark School of Engineering, the University of Maryland based in College Park, MD, USA, and chair of the VFS's eVTOL Technical Committee. Relying on batteries made for cars will continue to limit this technology, said Datta. “You cannot just take batteries developed for cars and put them into airplanes. Particularly in eVTOL, the power-plant and the aircraft must be designed together, not as isolated pieces. We're still far from optimal.”

While the weight of batteries is not a fundamental constraint for electric-powered ground transportation, weight is paramount



Fig. 1. (a) Archer Aviation's Maker aircraft, an 80%-scale demonstrator craft during a hover test flight. The six rotors on the front of the wing can tilt forward, turning into propellers for energy-efficient horizontal flight. Credit: Archer Aviation (public domain). (b) The similarly designed Vertical Aerospace VA-X4 will have its first test flights this year. Credit: Vertical Aerospace (public domain).

in aviation. The crucial task is to pack as much energy into as little mass as possible—to maximise specific energy—in a battery structure that allows delivery of sufficient power to the aircraft's rotors. For the fully-battery-powered eVTOL market to really take off will require much lighter batteries, but that “still requires fundamental scientific discovery,” said Anderson, who is also co-founder and chief technology officer of VerdeGo Aero (Daytona Beach, FL, USA), a start-up working to develop hybrid-electric propulsion technologies for new generations of aircraft.

Indeed, “range anxiety,” the scourge of owners of early electric cars, weighs heavy on the minds of eVTOL engineers. For Archer's Maker aircraft, which will carry four passengers and a pilot, the company claims a range of 97 km, and speeds of up to $241 \text{ km}\cdot\text{h}^{-1}$ in cruising mode [16]. For its 7-seater Lilium Jet, by comparison, Lilium promises a maximum range of 250 km, and a cruising speed of $282 \text{ km}\cdot\text{h}^{-1}$. In July 2021, Joby published details of a full-scale test flight of 248 km on a single battery charge, including a vertical take-off and landing, albeit remotely piloted and without any passengers [17]. With that, company founder and chief executive officer JoeBen Bevirt somewhat hyperbolically declared: “We have achieved something that many thought impossible with today's battery technology. By doing so we have taken the first step towards making convenient, emissions-free air travel between places like San Francisco and Lake Tahoe, Houston and Austin, or Los Angeles and San Diego an everyday reality” [17].

Before these aircraft can carry paying customers, they need regulatory certification, and none has yet been fully certified. And when it comes to meeting the requirements of certification from regulatory bodies, range is a problem, said Anderson. For example, the US Federal Aviation Administration (FAA) requires that, under daytime visual flight rules, aircraft have enough fuel for at least 30 min of reserve flight, and 45 min at night or flying

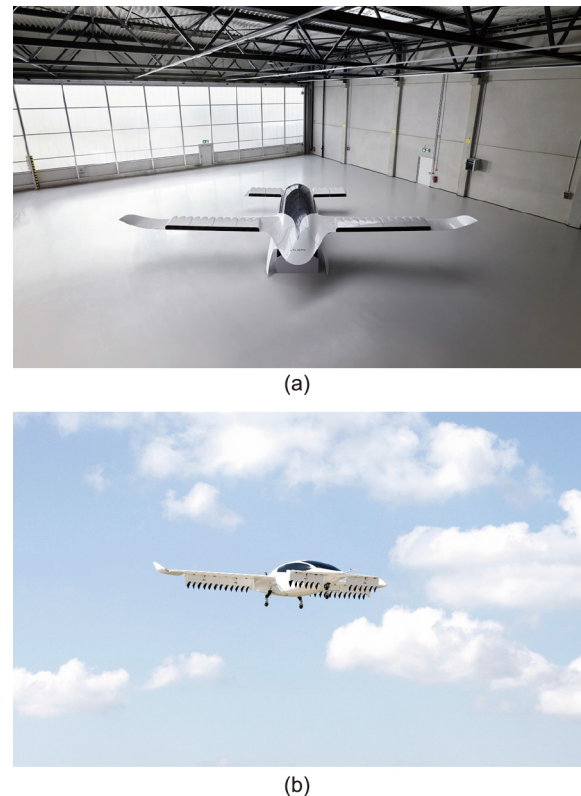


Fig. 2. (a) The rear view of a full-scale model of the 7-seater Lilium Jet at the company's headquarters in Munich, Germany, with its embedded, distributed propulsion and no tail. (b) Lilium's technology demonstrator aircraft during a test flight in Germany in 2021. Its 36 ducted electric fans are vertical here, enabling hover mode. Credit: Lilium (public domain).

on instruments alone [18]. If eVTOL manufacturers are bound by this same rule, a large part of their battery power would be reserved for emergencies, effectively slashing their practical range. “The FAA is going to be reticent to change rules written in blood,” said Anderson. “Do you really want to fly on a commercial aircraft that would normally be required to have a 45 min reserve if somebody has convinced those folks to allow it to be 5 min?”

Datta's view is that regulators like the FAA can accelerate the growth of this new industry, but that eVTOL manufacturers will have the burden of proof of safety. “Current regulations were not written for electric flight, so new rules are needed,” he said. “The faster the demonstrators are flown and tested, the faster we will arrive at consensus standards upon which to build these rules.”

Achieving certification will dictate when these aircraft fly commercially, and the process differs between regions. In the United States, some aspects of eVTOLs can be certified using existing FAA requirements, while the many novel aspects—such as distributed propulsion, fly-by-wire flight-control systems, and noise standards—must be developed with regulatory collaboration [19]. In contrast, the European Union Aviation Safety Agency (EASA) has reviewed “more than 150 VTOL project configurations, at different stages of maturity,” to develop a complete set of technical specifications dedicated to eVTOL-type aircraft that designates them as “Special Category” aircraft [20]. The EASA has also “largely harmonized” their specifications with the FAA's Part 23 [21], which covers airworthiness standards for small airplanes. Perhaps affecting the certification process, safety could likely be a benefit of using multiple electric motors—each of which has very few moving parts—in combination with distributing propulsion across many individually controlled rotors. Electric motors need less

maintenance, and larger numbers of them mean greater redundancy, should an individual motor fail [22]. Finally, the pilotless, autonomous aircraft under development will almost certainly face additional scrutiny and longer pathways to commercial use, although the Chinese Aviation Administration in February 2022 formally adopted and published “Special Conditions” that EHang states should provide the basis for certification of its two-seater EH216-S autonomous aerial vehicle [23].

Archer says it expects to have its aircraft fully certified and transporting paying customers across multiple US cities by 2024 [24]. Lilium, too, targets its commercial launch for 2024 [25]. But with the sheer number of novel design aspects in play with eVTOLs, such swift certification would be an enormous surprise, said Anderson. “For this whole class of battery-only eVTOL aircraft, these sorts of timelines are not even in the neighborhood of reality—this is going to take until 2030 to play out.”

Datta said that the eVTOL industry’s ambitious dates might have additional purposes: “Beyond the noble intent to decarbonize quickly, it might put pressure on regulatory bodies for swift action, and perhaps engender investor confidence.”

Certainly, investor confidence is high—higher than perhaps warranted. As aviation analyst Richard Aboulafia put it on the Aviation Week’s Check 6 Podcast in March 2021 [26]: “There is no functioning market and yet billions of dollars are pouring in—this is setting us up for the mother of all bubbles.”

For eVTOL makers to create a successful market, they must secure not only regulatory acceptance, but also public acceptance. eVTOL will need to be discreet to fit into urban life. “These new vehicles could bring financial, societal, and environmental benefits, but noise could lead to a lot of problems in exposed communities,” said Antonio Torija-Martinez, lecturer in acoustic engineering at the University of Salford Acoustics Research Centre in the United Kingdom and a member of the US National Aeronautics and Space Administration-led Urban Air Mobility Noise Working Group.

Electric motors are intrinsically much quieter than internal combustion engines, but the fundamental physics of rotors displacing air means some noise is inevitable. The contribution of electric motors to overall noise emissions is uncertain, but manufacturers are keen to claim that their aircraft will not disturb people unduly. Lilium claims noise around 60 dBA while its eVTOL hovers at 100 m [25], about the volume of a typical conversation happening a meter away [27]. Archer claims its aircraft will have a perceived volume of 45 dBA on the ground when cruising at 600 m, like the hum of a refrigerator [28]. “With smaller rotors than conventional helicopters, and more blades, eVTOL aircraft will produce higher-frequency noise, which is an important contributor to noise annoyance. Atmospheric absorption is really good at attenuating high frequencies, but the extent of high frequency noise reaching exposed communities remains to be determined,” which will require verifiable test data, said Torija-Martinez.

While eVTOL makers have garnered much breathless media coverage, they are not the only ones innovating in electric air travel. For example, United Airlines announced a deal in July 2021 to acquire 100 19-seat electric airliners from Heart Aerospace of Gothenburg, Sweden, subject to the aircraft meeting specific standards; the airline intends to put those planes into operation in 2026 [29]. And Kadima, Israel-based Eviation Aircraft Ltd., is approaching readiness for test flights of its nine-seater, all-electric propeller plane, called Alice [30].

In addition, cutting-edge performance has been demonstrated by the Spirit of Innovation all-electric aircraft (Fig. 3) made by Rolls-Royce, headquartered in Goodwood, UK, and partially funded by the UK Government-backed Accelerating the Electrification of Flight (ACCEL) project. In November 2021, the plane smashed two airspeed world records, averaging 556 km·h^{−1} over 3 km (beating the previous record by 213 km·h^{−1}) and 532 km·h^{−1} over



Fig. 3. Rolls-Royce's Spirit of Innovation all-electric aircraft during airspeed record-breaking runs at the UK Ministry of Defence's Boscombe Down experimental aircraft testing site. Credit: Rolls-Royce (public domain).

15 km; in addition, its top speed of 623 km·h^{−1} made it the world's fastest all-electric vehicle [31].

Precisely how many years will pass before eVTOL air taxis and short-range electric commuter planes flit through the skies remains an open question, but they are undoubtedly on the horizon. Just do not expect too much too soon, said Datta. “It is a cliché with new technologies, but right now I think companies are overestimating the short-term impact and governments are underestimating the long-term impact.”

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