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ELECTRIC AIRCRAFT START TO "AMP" UP!

By Erin I. Rivera

According to Richard Branson, "If you want to be a millionaire, start with a billion dollars and launch a new airline." This is one of those "funny because it's true" sayings. The idea applies equally to most new undertakings in aviation, including the design, certification and manufacture of a new aircraft. In this article, we will examine one of the most ambitious initiatives in modern aviation: electric aircraft and urban air mobility.

We aim to update readers on current developments in electric and hybrid-electric aircraft as well as examine what we can expect from the first generation of eco-friendly aircraft. We will also take a look into electric Vertical Take-Off and Landing (eVTOL) aircraft and the developments occurring in Urban Air Mobility (UAM). Finally, we discuss the Federal Aviation Administration's (FAA) certification process, its application to eVTOL aircraft and the certification challenges applicable to eVTOL aircraft currently in development.

The High Cost of Business as Usual

One of the main barriers to aviation innovation has been the aircraft certification process, which often stopped dead innovation in aircraft design before it even left the drawing board. The Federal Aviation Administration's (FAA) certification regulations – which provide IKEA®-like, step-by-step instructions for building, designing and testing an aircraft – often penalize the introduction of new technology. If the aircraft design or technology does not fall squarely within the certification regulations, then designers can expect to incur additional time and cost to satisfy the FAA's inquisition (e.g., Issue Paper process, Equivalent Level of Safety (ELOS), Special Conditions).

Certifying an aircraft is an extraordinary feat, requiring countless engineering and flight test hours, thousands of regulations and a very large checkbook. A recent **publication** by *Aerospace Testing International* reported "certification costs around $1 million for primary category aircraft, which have up to three seats, $25 million for a general aviation aircraft and hundreds of millions of dollars for a commercial aircraft."[1] Of course, this is just for certification and these figures do not factor in delays due to redesign changes, additional flight testing, special conditions, etc., which typically happen and can add millions more to certification costs.

[1]Aerospace Testing International, "*Certifiably Cheaper*," pg. 38 (last accessed Jan. 3, 2020), http://viewer.zmags.com/publication/103c30e3#/103c30e3/40.

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Because of the high price of certification, the latest and greatest technologies often skips aviation, which is why a new Cessna 172 still looks pretty much the same as it did when the C-172 was type certified in 1955: a single-engine propeller and fixed-wing aircraft with the usual stick and rudder flight controls. Don't get me wrong, I love flying the 172. It's a great aircraft and, throughout the years, Cessna has produced upgraded models with improved avionics. But the C-172, at its heart, is still the same 1955 aircraft ... at least according to its type certificate (TC).

Planting the Seeds of Change

Come 2020, that's all going to change (actually, it changed in 2017 with the **rewrite to 14 CFR Part 23**, but 2020 sounds much cooler)! Companies like Eviation Aircraft with its all-electric fixed-wing aircraft and Uber Elevate are pushing a new technologically advanced class of electric aircraft into the aviation ecosystem. But how close are we to the reality of commercial flight in an electric aircraft? What can we expect for the first generation of hybrid and all-electric aircraft?

By late 2021 or early 2022, **Eviation Aircraft** expects 14 CFR Part 23 certification of its all-electric nine-seat aircraft, known as Alice. Driving the two Hartzell propellers at the wingtips and one in the rear fuselage are three electric motors supplied by MagniX or Siemens. Powering the all-electric aircraft will be a 900 kilowatt-hour (kWh) lithium-ion (Li-ion) battery system weighing 8,200 pounds, which accounts for 60% of the aircraft's maximum take-off weight (MTOW). Additionally, Alice will implement fly-by-wire technology and automated landing capabilities.

Eviation lists a cruise airspeed of 260 knots and a range of 650 miles for Alice, which is ideal for regional air carriers like Cape Air – the company **announced** as the first commercial customer for Alice.[2] Eviation also has plans for an upgraded 2.0 version of Alice – Alice ER – which will have a pressurized cabin and an upgraded aluminum-air battery system, increasing the aircraft's range to **738 nautical miles**. As of January 2019, Eviation **secured $200 million** in funding for certification and production of Alice. **Flight testing** for Alice will take place at Moses Lake's Airport in Seattle.[3]

The Need for Improved Li-Ion Battery Technology

Plans are underway for developing even larger capacity aircraft (100+ passengers) by several aerospace companies, but initial designs will be hybrid-electric rather than all-electric due to current limitations in battery technology. In a nutshell, current Li-ion batteries do not provide the same bang for your buck as hydrocarbon fuels. The power provided by today's Li-ion batteries is suitable for smaller aircraft with a five or less passenger capacity, but gravimetric energy density (battery power expressed as watt-hours per kilogram (Wh/kg) is not sufficient for an all-electric aircraft in the transport size category.

The best Li-ion batteries currently have energy densities of about 250 Wh/kg, which, depending on the aircraft design, equates to a range of around 300-600 miles for electric aircraft (less for non-wing-born lift designs, such as multi-rotors) on a single charge.

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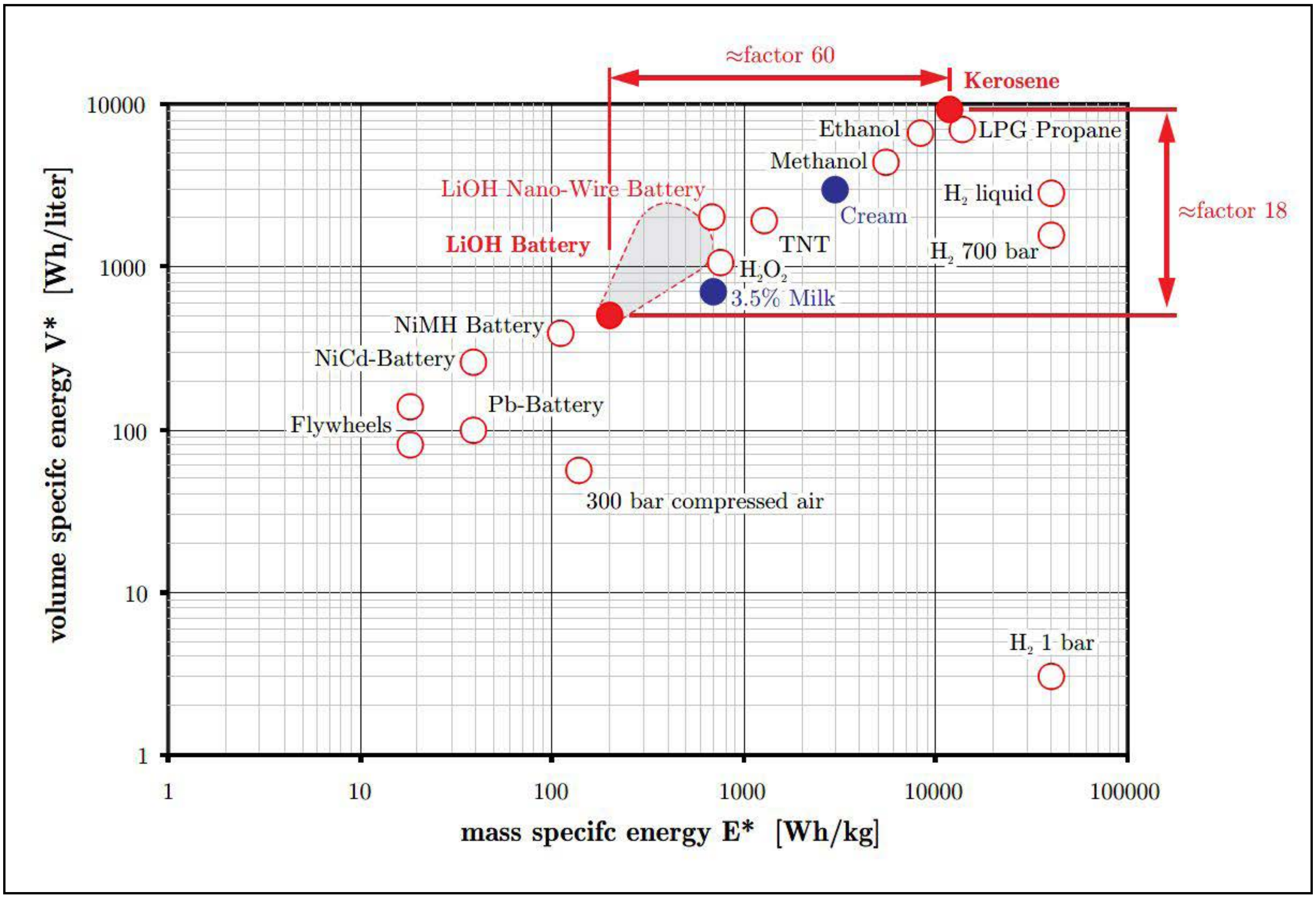
[2]AINonline, "*Eviation's Alice to Fly This Year*," (last accessed Jan. 3, 2020), https://www.ainonline.com/aviation-news/air-transport/2019-06-19/eviations-alice-fly-year.
[3]Geek Wire, "*Eviation unveils electric airplane and plans flight tests in central Washington state*," (last accessed Jan. 3, 2020), https://www.geekwire.com/2019/eviation-unveils-electric-airplane-plans-flight-tests-central-washington-state/.



*Graphic Source: "**Electric Flight – Potential and Limitations**," M. Hepperle, AVT-209 Workshop on Energy Efficient Technologies and Concepts Operation, Lisbon, October 22-24, 2012. Reprinted with permission.*

The above chart is somewhat dated but still valid. It represents essentially where we are in battery technology and how far we still need to go before batteries become a suitable replacement for all aspects of aviation transportation. By comparison, Tesla's most advanced Li-ion batteries have an energy density just shy of 250 Wh/kg. Innolith, a Swiss tech startup, announced in April 2019 that its non-flammable inorganic Li-ion battery achieved an energy density of **1,000 Wh/kg**. If confirmed, the Innolith battery will be a breakthrough in Li-ion technology that speeds up the current battery development trend, which currently tracks a 5-8 % **increase in gravimetric energy density** annually. The next generation Li-ion batteries (e.g., lithium-air or lithium-sulfur) intended for electric aircraft are expected to reach energy densities of 750-1000 Wh/kg. All in all good news, but we are still a long way from the energy density of jet fuel at 13,500 Wh/kg.

Transport Category Electric Aircraft

Larger transport category size aircraft (i.e., regional and large commercial aircraft) are unlikely to leap directly to all-electric propulsion. Rather, the first steps will likely be a hybrid system (think Prius rather than Tesla) that utilizes both conventional and electric engines in parallel or series hybrid configurations. One such initiative – Project 804 – undertaken by United Technologies (UT) Research Center, and UT subsidiaries Collins Aerospace and Pratt & Whitney, involves the conversion of a Dash-8 Series 100 aircraft to a hybrid-electric demonstrator for 30-50-passenger regional capacity flights. **Project 804's** "mission is to achieve hybrid-electric flight by 2022, and to enable certified hybrid-electric regional travel within 10 years."[4]

Similarly, Airbus, in collaboration with Rolls-Royce and Siemens, is developing a commercial 100-passenger hybrid-electric aircraft known as the **E-Fan X**, scheduled to take its first test flight in 2021 with expectations of commercial passenger flights in the 2030s timeframe.[5] The E-Fan X is more of a "let's dip our toes in the water" approach since only one of its four engines is hybrid-electric.

EasyJet, a British low-fare airline carrier, is also assessing the potential for hybrid and hybrid-electric aircraft for short-haul flights across Europe. In 2017, EasyJet **announced a partnership with Wright Electric** to develop a 150-seat electric plane with a range of 300 miles by 2027.[6] In November 2019, EasyJet and Airbus signed an MOU to "jointly assess the potential of hybrid- and full-electric aircraft for short-haul flights across Europe."[7]

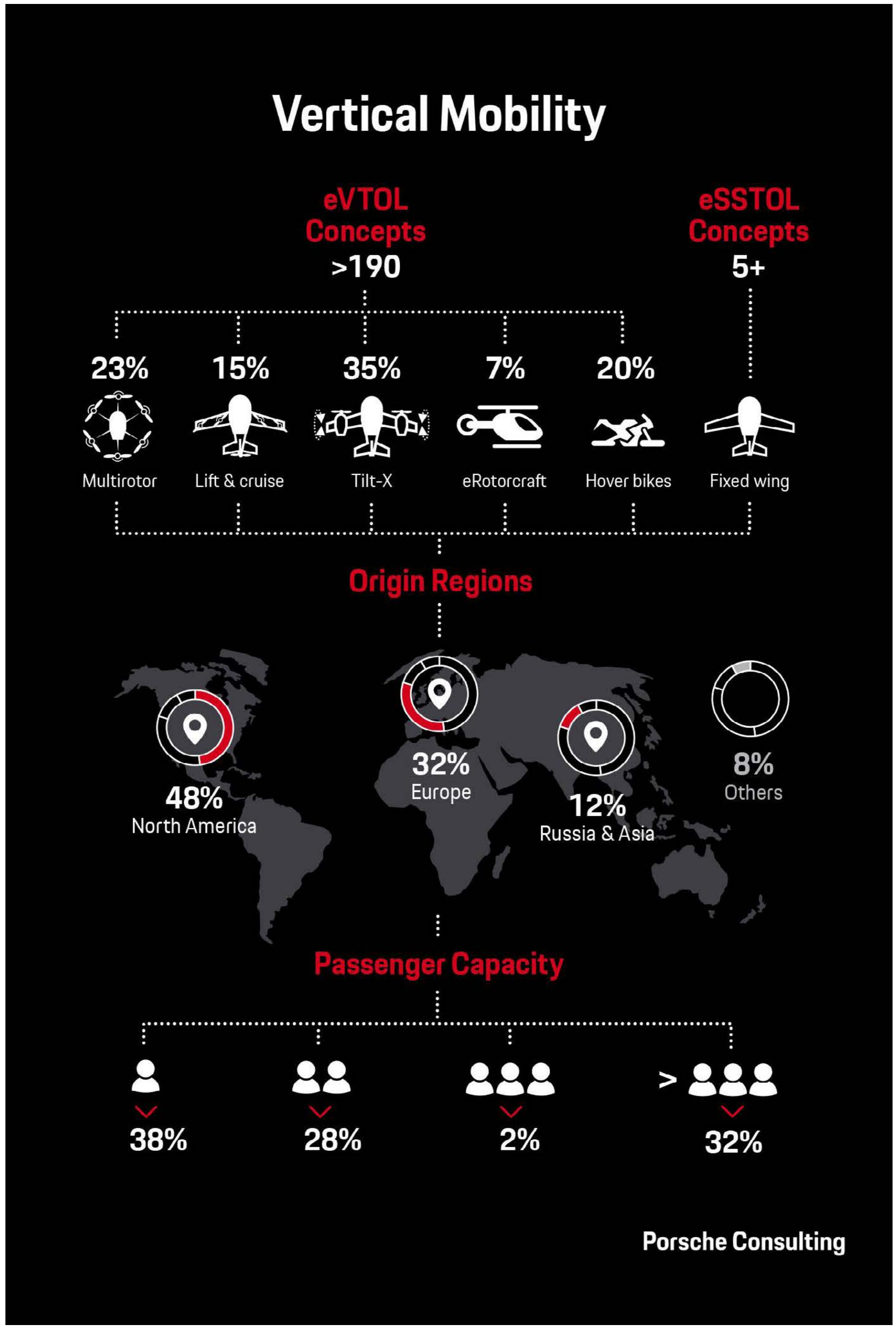
[4] United Technologies, "*Project 804*" (last accessed Jan. 3, 2020), https://www.utc.com/en/news/2019/06/17/airshow-p804.
[5] Airbus website, "*E-Fan X*," (last accessed Jan. 3, 2020) https://www.airbus.com/innovation/future-technology/electric-flight/e-fan-x.html.
[6] Wright website, "*Lower cost, quieter flight, cleaner future*," (last accessed Jan. 3, 2020) https://weflywright.com/.
[7] Bristol Airport, "*EasyJet and Airbus sign hybrid and electric aircraft research agreement,*" (last accessed Jan. 3, 2020), https://www.bristolairport.co.uk/about-us/news-and-media/news-and-media-centre/2019/11/easyjet-and-airbus-sign-hybrid-and-electric-aircraft-research-agreement

eVTOL Aircraft

According to the **Electric VTOL News**, there are currently more than 200 electric and hybrid-electric Vertical Take-Off and Landing (VTOL) concepts in various stages of development from the automotive, aviation and the tech industries. The adjacent chart – which tracks 190 eVTOL and five eSSTOL (SS = super short) concepts – the majority of the projects are originating from the United States (48%) and Europe (32%).

Major aviation industry players – including **Aurora Flight Sciences (Boeing)**, **Bell**, **EmbraerX**, **Karem Aircraft**, **Pipistrel Vertical Solutions** and **Jaunt Air Mobility** – are partnering with **Uber Elevate** on developing eVTOL designs. The aircraft vary in performance, (depending on their mission type), but will meet Uber's specific Urban Air Mobility (UAM) vehicle requirements found **here**, which includes a 150 mph cruise speed, 60-mile sizing range, a three-hour sprint of 25-mile trips, VTOL capabilities and capacity for one pilot and four riders.[8]

Safety, battery efficiency and speed are at the top of the must-have list in eVTOL design, which makes Multirotor and Tilt-X VTOL configurations the favorites. The Multirotor design provides increased safety due to its redundant systems, while the Tilt-X provides a superior energy-efficient design that maximizes battery life, speed, and range by relying on wing-born lift generated during cruise flight.



*Graphic Source: "**Vertical Mobility**," Porsche Consulting. LinkedIn Post. Reprinted with permission.*

[8]Uber website, "*UberAir Vehicle Requirements and Missions*," (last accessed Jan. 3, 2020), https://s3.amazonaws.com/uber-static/elevate/Summary+Mission+and+Requirements.pdf.

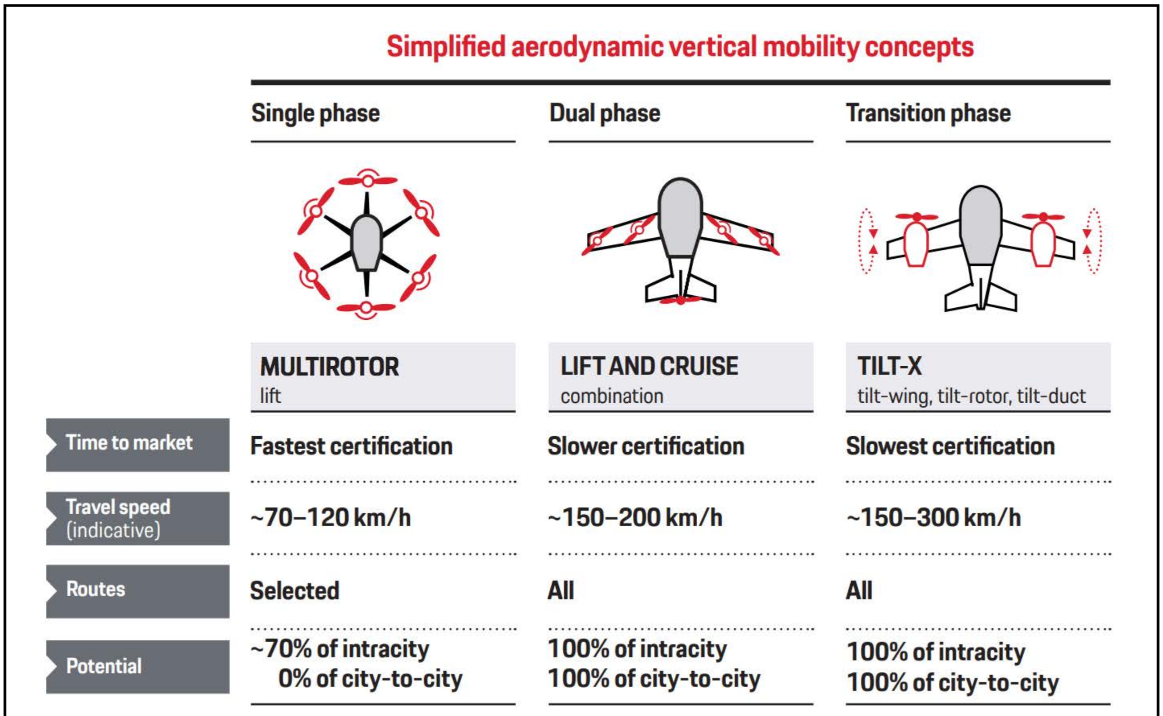


Figure 6. Faster and further: the three basic aerodynamic concepts for drones, each with pros and cons. Graphic: Porsche Consulting

*Graphic Source: **"The Future of Vertical Mobility,"** Porsche Consulting, 2018. Reprinted with permission.*

Certain eVTOL designs such as the Bell Nexus with its six overhead ducted fans will be ideal for short flights in and around the city due to its multi-rotor configuration. On the other end, the Pipistrel 801 will be better suited for long haul flights due to its ability to transition after take-off to wing-born lift for cruise flight with the use of just one pusher propeller.

By 2023, Uber expects to have aerial ridesharing networks in Dallas, Los Angeles and Melbourne, Australia, with demonstrator flights planned for as early as 2020, according to the Uber Elevate website. For Dallas, Uber plans on at least six vertiports, with the first of them being built at **Frisco Station**. According to a recent **article**, additional vertiport locations will be in downtown Dallas, Plano, Fort Worth, and at Dallas Fort Worth International Airport.[9]

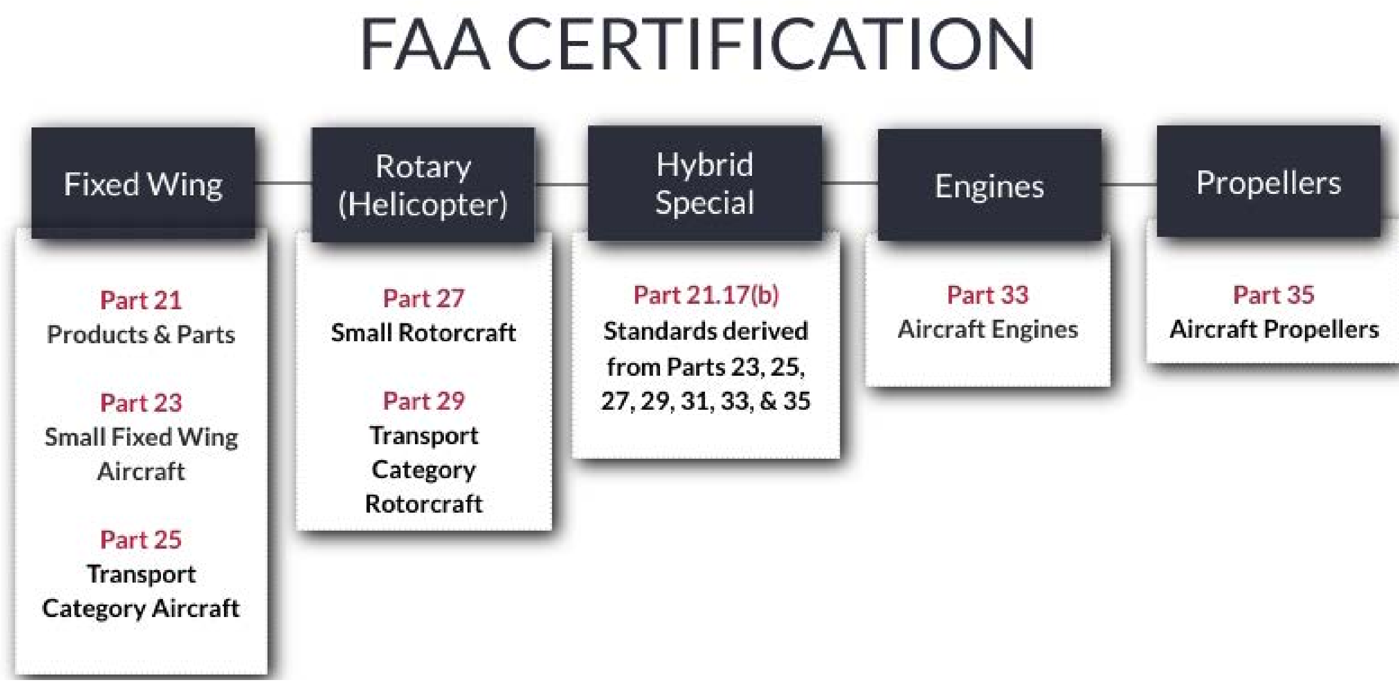
Outside the U.S., companies like **Volocopter** and **Lilium** are not far from commercial production of their ultra-redundant eVTOL air taxis. Volocopter, a German-based startup, incorporates 18 electric motors/rotors in its two-passenger eVTOL design. In August 2019, Volocopter revealed its first commercial air taxi called the **VoloCity**, which meets the European Aviation Safety Agency's (EASA) **SC-VTOL certification standards**. For flight testing, Volocopter is still using its earlier "2X" eVTOL, which completed its first manned flight over Singapore's Marina Bay on October 22, 2019.[10]

Lilium, another German startup expects its five-seater eVTOL aircraft – powered by 36 all-electric turbines – to be operational by 2025. The Lilium concept was awarded the 2019 **Red Dot: Best of the Best Design Award**, which is not surprising considering that Lilium's design team includes **Frank Stephenson**, the world-renowned designer of the BMW X5, the Ferrari F430 and the McLaren P1. Lilium intends to use off-the-shelf battery technology to reach its 300 kph speed and 300-kilometer projected range on just one battery charge.[11] Lilium, however, isn't disclosing the aircraft's weight or battery specs (perhaps they haven't quite settled on a battery design).

[9]AINonline, "*Uber Seeks More eVTOL Partners for Ride-share Program,*" (last accessed Jan. 3, 2020), https://www.ainonline.com/aviation-news/business-aviation/2019-09-04/uber-seeks-more-evtol-partners-ride-share-program.
[10]Volocopter website, "*Volocopter air taxi flies over Singapore's Marina Bay,*" (last accessed Jan. 3, 2020), https://press.volocopter.com/index.php/volocopter-air-taxi-flies-over-singapore-s-marina-bay
[11]Lilium website, "*Lilium Jet awarded…*," (last accessed Jan. 3, 2020), https://lilium.com/newsroom-detail/lilium-jet-awarded-prestigious-red-dot-best-of-the-best-design-award

FAA Certification

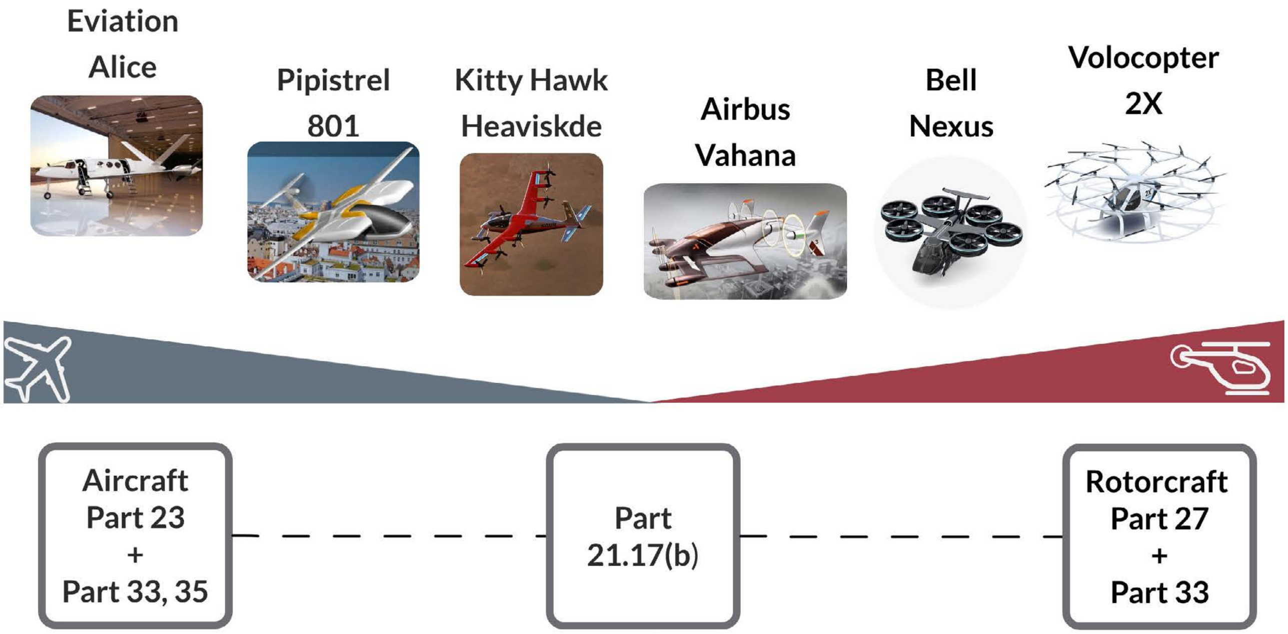
So what has to be done before you can hail an air-taxi on your phone? For companies that wish to operate in U.S. airspace, their aircraft will need an airworthiness certificate from the FAA before they can begin commercial operations, i.e., carrying paying passengers. Fixed-wing aircraft under 19,500 pounds and a passenger seating configuration of 19 or less are certified under Part 23 of the Code of Federal Regulations. Small Rotorcraft (i.e., helicopters) are certified according to Part 27 airworthiness standards. Aircraft certifying under Part 23 or Part 27 must also comply with Part 33 (engine) and Part 35 (propeller) certification requirements as applicable.



The certification framework for VTOL (especially eVTOL) aircraft is not as black and white since the VTOLs, by design, share a bit of both Part 23 and 27. The general rule is that if the eVTOL capable aircraft flies most of its flight profile in wing-born lift – e.g., Lift & Cruise or Tilt-X designs – Part 23 will probably apply. However, if the eVTOL aircraft flies its whole flight under thrust – e.g., multirotor with no wing-lift component – then it's probably a rotorcraft and Part 27 applies.

Another potential certification route for eVTOL aircraft is [Part 21.17(b)](), which applies to special classes of aircraft for which certification standards may not exist, e.g., gliders, airships, tiltrotors. Certification under Part 21.17(b) depends on the aircraft, its intended use, and area of operation (i.e., risk class). Aircraft are then certified according to existing airworthiness standards derived from Parts 23, 25, 27, 29, 31, 33 and 35, as appropriate, in addition to using or creating airworthiness standards to address unique VTOL features and characteristics. For example, the Part 23.17(b) certification process for the AgustaWestland AW609 Tiltrotor VTOL included certification standards for transport category aircraft (Part 25) and transport category rotorcraft (Part 27) in addition to standards developed specifically for the transition phase between aircraft and helicopter configurations unique to the tiltrotor design. In addition, VTOL and eVTOL designs must also comply with Part 33 (engine) and Part 35 (propeller) if applicable.

Regarding eVTOLs under 19,500 pounds with a passenger-seating configuration of 19 or less, Part 23 (aircraft) standards applicable to wing-born flight will apply, while the VTOL aspects will likely be certified using Part 27 (rotorcraft) standards. Like the tiltrotor, specific certification standards will need to be developed to cover specific safety requirements for eVTOL systems and flight characteristics.



14 CFR Part 23, Amendment 64

To allow more flexibility for new technology in aircraft designs, the FAA amended 14 CFR Part 23 (Airworthiness Standards for General Aviation Aircraft), which took effect in August 2017. The rewrite of the regulations, which took nearly 10 years, was partly due to the efforts by companies like Uber and Piper Aircraft, Inc. who recognized a major change in small aircraft certification process was necessary to enable the development of UAM aircraft.

Now in place are 71 performance-based regulations that may be satisfied through more than one means of compliance (MOC). These can include the use of industry consensus standards, FAA advisory circulars, or applicable regulation. The FAA issues guidance on acceptable MOCs and maintains a partial list of accepted standards that can be found **here**.[12] As of July 2018, the FAA had accepted 63 industry consensus standards drafted by ASTM International as MOCs that can be used for complying with Part 23 airworthiness standards. The 63 industry consensus standards are a start in the right direction, but there are no accepted consensus standards for key aspects of tomorrow's eVTOLs, including autonomous (unmanned) systems, electric propulsion systems (EPU) and energy storage systems (ESS).

Aircraft seeking certification under Part 23 must also comply with Part 33 (engine) and Part 35 (propeller) certification requirements. Outlined in 14 CFR Part 33 are the airworthiness standards for aircraft engines, which have not been overhauled to address certification standards for electric or hybrid-electric propulsion units.

There are consensus standards developed by ATSM (Subcommittee F39.05 and F44.40) for the design and manufacturing of EPU and ESS systems for general aviation aircraft. These consensus standards, however, have not been accepted (yet) by the FAA as a MOC with Part 33. Thus, applicants seeking type design approval for EPUs will need to work closely with the FAA to identify any significant issues (i.e., Issue Paper process) and establish special conditions for the "novel or unusual" design features of the product to achieve type certification. (AC 20-166A(5)(g))

Ultimately, applicants, i.e., the individual or company seeking a type certificate under Part 23, must demonstrate through an MOC process that their proposed design achieves its design criteria while maintaining the same level of safety that currently exists for all aircraft certified under Part 23. One obvious safety concern with eVTOL aircraft is the crashworthiness of the Li-ion energy storage systems (ESS).

[12]FAA website, "*Part 23 Accepted Means of Compliance….*," (last accessed Jan 3, 2020), https://www.faa.gov/aircraft/air_cert/design_approvals/small_airplanes/small_airplanes_regs/media/part_23_moc.pdf.

Li-ion batteries damaged in a crash can result in thermal runaway, also known as venting with flame. Rotorcrafts subject to Part 27 are required to undergo multiple 50-foot drop tests without rupture of the fuel system to achieve certification. Assuming the Part 27 drop test is applicable for eVTOL certification, the battery system will need to demonstrate accident survivability – a current concern with Li-ion battery systems.

Achieving aircraft type certification will indeed be a significant accomplishment for electric Conventional Take-Off and Landing (CTOL) and eVTOL aircraft. However, type certification is just one of the three steps necessary before production and aircraft deliveries can take place. eVTOL manufacturers intending commercial production will also need a production certificate and each aircraft will also need an airworthiness certificate. The production certificate demonstrates to the FAA that the manufacturer is capable of mass reproduction of the aircraft to the same standards and can be almost as difficult to obtain as the aircraft type certificate. Finally, eVTOL intended for commercial use (i.e., Part 135) will be subject to further scrutiny to include additional safety, performance, maintenance, and operational requirements depending on its passenger capacity and commercial use.

Conclusion

Initial electric aircraft designs will have the same certification and regulatory requirements as every other type of aircraft. Commercial flight operations, conducted under Part 135, will require much of the same operational safety requirements as today's on-demand charter operations. Although, the intent of eVTOLs is to be autonomous (i.e., pilot-less) in the future, the current crawl, walk and run approach will require an onboard commercial or ATP trained pilot that will be phased out over the span of 10 years or so. Some familiarity with today's air travel will need to be maintained until society can accept electric aircraft and UAM as a common multimodal form of transportation. Until then and beyond, safety will be paramount to the success of electric aircraft and the UAM industry.

About the Author

Erin I. Rivera holds a deep understanding of industry standards and aviation sector challenges based on lifelong interaction and familiarity with the business. He has more than a decade of legal experience in the aviation and insurance industries. Clients rely on him to assist with regulatory compliance, aviation safety, aviation accident investigations, insurance and complex aviation litigation. Erin is frequently involved in assisting clients during NTSB and US military aircraft accident investigations.

Erin is also particularly well-versed in the current developments in small aircraft and parts certification, aviation technology, urban air mobility (UAM) initiatives and electric Vertical Take-Off and Landing (eVTOL) aircraft.

Holding an FAA private pilot license, Erin has previously interned as an air accident investigator with the National Transportation Safety Board. He also served in the U.S. Air Force as a helicopter flight engineer on board the Sikorsky HH-60G PaveHawk.

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