Vertical Aerospace is one of many companies working on designs for all-electric eVTOL aircraft with motors positioned by each of several open rotors.

MAY 2020

FutureFlight | SPECIAL REPORT

POWER TECHNOLOGY

Battery technology is still falling short as a long-term answer to the needs of electric aircraft. Lighter, more capable batteries—or alternatives like hydrogen fuel cells—will be needed to allow aircraft to fulfil their potential to reduce aviation's carbon footprint. For now, hybrid electric propulsion seems the most viable option for many new aircraft developers.

POWER TECHNOLOGY

Of all the technologies being honed to enable the aviation revolution promised by new-generation electric aircraft, it is power that offers both the greatest potential for progress while also posing the biggest challenges. For all the hype about electric aviation, it is hard to make a case that current battery technology is a sufficiently firm foundation to support more than a fairly narrow business model for all-electric aircraft in the next few years.

That's not to say it will always be this way, but clearly the industry is facing a significant investment and learning curve before commercially and technically viable power source solutions are readily available. Plenty of effort is now being applied to taking battery technology to another level, while some pioneers are working on alternatives such as hydrogen fuel cells.

However, it's hard to envision that a quantum leap on either front is just around the corner. That's why so many of the estimated 200 electric vertical takeoff and landing aircraft programs are being developed, at least initially, to have a hybrid electric powerplant in which a conventional motor generates electricity. Those aircraft developers sticking with an all-electric plan from the outset have acknowledged that they will need to confine themselves, for now, to

The Lilium Jet is powered by 36 electric motors mounted on flaps that provide vertical or horizontal thrust as the wings are tilted.

the somewhat closely concentrated urban air mobility (UAM) market for flights of no more than around 30 miles. This includes some of the sector's apparent early leaders, such as Volocopter, EHang and Lilium Jet.

The automotive sector gives its cousins in aviation reasons to be optimistic about the potential for the right level of electric power technology to become available. Electric cars are becoming ever more mainstream, with more and more market observers saying that the tipping point transition away from fossil-fueled cars is within sight on our highways.

In November 2019 automaker Ford released an all-electric variant of its iconic sports car, the Mustang. In 2018 electric car maker Tesla built 350,000 cars, and revenues for the electric car industry topped $21 billion, with one-fifth of those going to Mercedes. There are now more than one million electric cars in the U.S. and more than five million worldwide—an increase of two million from the previous year. And this geometrically growing sales trend is forecasted to continue. Annual worldwide sales of ground electric vehicles are expected to reach 27 million by 2030. By then there will be 125 million electric vehicles on the road, according to the International Energy Agency.

The future of all-electric passenger air vehicles is less certain for now. The chief reason is that current lithium-ion (Li-ion) battery technology is neither realistically economical nor satisfies reasonable requirements for range and flight duration.

FOR NOW, MOST ALL-ELECTRIC EVTOL PROTOTYPE DEPEND ON BATTERIES THAT LIMIT THEIR FLIGHT DURATION TO 30 MINUTES.

For now, most all-electric eVTOL prototypes depend on batteries that limit their flight duration to 30 minutes. Coincidentally, that's the same amount of mandated Visual Flight Rules (VFR) daylight fuel reserves currently mandated by the U.S. Federal Aviation Administration (FAA) for civil fixed-wing aircraft. The reserve bumps up to 45 minutes at night and the required reserve for daylight VFR helicopters is 20 minutes.

"There are limitations as to what we can do with batteries," acknowledges Amanda Simpson, Airbus Americas vice president for research and technology. "The [UAM prototype] vehicles that are out there have a range of about 30 miles. Trying to get more than 30 minutes to an hour our of a vehicle the size [of the two-seat Airbus Vahana technology demonstrator eVTOL] is very challenging today. The battery technology is going to have to come along much further if we are going to have 100 percent electric vehicles."

BATTERIES: TOO HEAVY, TOO SLOW TO CHARGE

The main problems are weight and charging times. The lithium-ion battery pack for a first-generation Nissan Leaf automobile weighs 648 pounds, about 50 pounds more than the batteries required to power the two-seat Vahana 30 miles. For an eVTOL aircraft to be able to carry between four and nine passengers they would need much bigger battery packs, heavier vehicles, and potentially longer charging times.

Battery management—using short charges between flights to optimize battery capacity–could solve part of the problem, according to battery expert Celina Mikolajczak, who has worked at Tesla and Uber Air and is now vice president of battery technology at Panasonic. But that attaches risks, she said at the 2019 Uber Elevate summit. “Fast charge is one of those things that can degrade a battery pack if you don’t do it properly,” she explained. Typically, that means not letting battery capacity fall below 50 percent.

John Badalamenti, Uber Elevate’s head of design for advanced programs, explained how multiple charging during the day would work with UAM. “It’s all about battery management. You start the day with a full charge, you drain it down to 60 percent, and then you recharge to 30,” he stated. “You continue that sawtooth model throughout the morning, then charge back up to 100 percent in the afternoon, repeat the sawtooth model, and then charge back up to 100 percent overnight.”

Theoretically, batteries that are continually operated and charged within a “sweet spot” could last as long as 10 to 12 months and electric vehicle superchargers could load a battery to 50 percent capacity within 20 minutes. Nevertheless, Mikolajczak is of the opinion that the battery technology needed to bring eVTOL into a commercially viable UAM application has yet to be invented.

THE BATTERY TECHNOLOGY NEEDED TO BRING EVTOL INTO A COMMERCIALLY VIABLE UAM APPLICATION HAS YET TO BE INVENTED.

BATTERY TECHNOLOGY

Traditional lead-acid batteries for aircraft and automobiles are based on a positive electrode—a positively charged lead oxide plate which is immersed in an electrolyte, typically sulfuric acid and distilled water. There is a positive lead alloy grid that serves as a current collector. There is also a negative electrode that consists of a pure lead negative plate immersed in the electrolyte, which can be liquid, gel, or bound in glass plate. Positive and negative plate sets are combined to form a battery cell. A typical 12-volt car battery has six cells that are connected in sequence.

A Li-ion battery uses a lithium compound at the positive electrode and graphite at the negative electrode. Lithium ions move from the negative to the positive electrode during discharge. While Li-ion batteries have a high energy density compared to lead acid batteries, the flammable electrolyte—typically mixtures containing ethylene or diethyl carbonates--can present a fire hazard if damaged or incorrectly charged. There are many different types of Li-ion batteries, with those that present less of a fire danger—those employing lithium nickel manganese cobalt oxide--typically sacrificing some energy density.

While Li-ion batteries offer a quantum jump in efficiency compared to traditional lead acid batteries, they still are wanting when it comes to delivering sufficient power for all-electric aircraft applications. However, work is proceeding on the development of improved battery technology that increases reliability, power, and decreases costs. But when and if some of these new technologies will become commercially available remains an open question, with some industry participants predicting a lag of anywhere from five to ten years.

Oxis Energy is developing a lithium-sulfur (Li-S) battery it claims will allow electric aircraft to fly between 50 and 100 percent longer, with an output of 500 Watt-hour per kilogram.

These technologies include the following:

- **Lithium metal anode.** Cuberg is developing a new battery that combines a lithium metal anode, proprietary electrolyte, and high-voltage cathode to achieve high energy density and thermal durability. The company has received a multimillion-dollar investment from Boeing. Cuberg says its design provides up to 70 percent more power than a comparable weight lithium-ion battery by using a stable electrolyte that remains stable even when run at excessive temperatures, preventing thermal runaway. “Cuberg’s battery technology has some of the highest energy density we’ve seen in the marketplace, and its unique chemistries could prove to be a safe, stable solution for future electric air transportation,” said Steve Nordlund, vice president of Boeing HorizonX, which is leading Boeing’s efforts in the eVTOL sector.

- **Lithium-Sulfur.** Oxis Energy is developing a lithium-sulfur (Li-S) battery it claims will allow electric aircraft to fly between 50 and 100 percent longer, with an output of 500 Watt-hour per kilogram. It has a partnership with Bye Aerospace to develop new batteries for its eFlyer fixed-wing aircraft. Li-S batteries are lightweight, due to the low atomic weight of lithium. Unfortunately, technical issues remain, including low battery life cycle and the need for a comparatively more electrolyte and therefore more battery mass.

- **Lithium-Oxygen.** This battery type uses nanoflakes of molybdenum disulfide to support the oxygen cathode, a dilithium carbonate protective layer on the lithium metal anode and an ionic liquid as the electrolyte. Lithium-oxygen has the potential to produce five times the energy of a traditional li-ion battery. “The very high theoretical energy density and low materials cost of lithium oxygen batteries are attractive for many applications including electric flight,” noted the authors a research paper titled, “Addressing the Challenges of Carbon-free Energy,” published earlier this year in the Proceedings of the National Academy of Sciences.

- **Foam coated with copper anode.** Prieto has designed a 3D battery that bonds copper antimonide onto an extremely porous foam substrate layered with a polymer electrolyte. The foam’s large surface area reduces required ion travel thus boosting energy density and power. These batteries are conceivably smaller, cheaper, non-flammable, easier to make.

Meanwhile, research also is continuing into the use of alternative metals and materials—including aluminum, magnesium, and silicone-- to lithium and graphite anodes in li-ion batteries as well as eliminating the use of lithium from the electrolyte or making the electrolyte a solid (solid state).

BEYOND BATTERIES

Hydrogen fuel cells have been employed with some success on small drones by companies such as EnergyOr and Skycorp, who report that endurance increases by factors of two to four over li-ion power. But powering eVTOL aircraft with fuel cells would be stymied by the current lack of a national aviation distribution system. In the U.S., currently only California has a network of around 50 locations that cater to automotive fuel cell users, while Japan has plans in work to build 2,000 of them over the next eight years.

However, as none of the new battery technologies are market-ready, OEMs with actual aircraft building experience such as Airbus and Bell have been prompted to examine hybrid/distributed power solutions for their first-generation eVTOL aircraft. Typically, such arrangements rely on using a fossil-fueled internal combustion engine (piston and turbines) as a generator to power the electric drive motors with some form of battery back-up. Aircraft engine makers Continental, General Electric, Honeywell, Pratt & Whitney, Rolls-Royce, and Safran are all working on hybrid/distributed power systems.

Safran is one of several aircraft engine makers working on new hybrid/distributed power systems for eVTOL aircraft, and the French company is already offering electric motors (like this one) for general aviation aircraft.

HYBRIDS AREN'T STRAIGHTFORWARD EITHER

Hybrid unmanned air vehicles (UAVs) clearly do not fit into the UAM model envisioned by ride-share giant Uber and some others. The planned Uber Air model relies on the use of existing rooftop and elevated structures such as parking garages to accommodate eVTOL takeoff and landings.

Fossil-fueled vehicles are likely to add wildly to estimated infrastructure costs unless used at existing airports and heliports due to various factors including the need for fossil fuel storage and refueling. The complex requirements for this infrastructure are laid out in documents such as the National Fire Protection Association standard 418 and the International Civil Aviation Organization's Chapter 6 rules for Heliport Emergency Response. Required equipment for rooftop structures includes safety nets, standpipes, and a fuel water separator tank, while best practices include the addition of a fire extinguishing foaming system. These additional costs are considerable.

Hybrid eVTOLs also are likely to produce more noise than models solely powered by batteries, and this is likely to incur public acceptance problems and outright political opposition, especially in helicopter noise-sensitive markets including New York and Los Angeles.

For these reasons, leading proponents of eVTOL aircraft as part of an integrated UAM system are reticent about hybrid technology. However, until battery technology improves, hybrids may be the only viable solution that meets mission range and duration requirements while satisfying regulators.

XTI Aircraft's TriFan 600 is an example of a hybrid eVTOL design and it is based on the company's ducted fan technology with GE Aviation's new Catalyst turboprop engine providing the main power source.