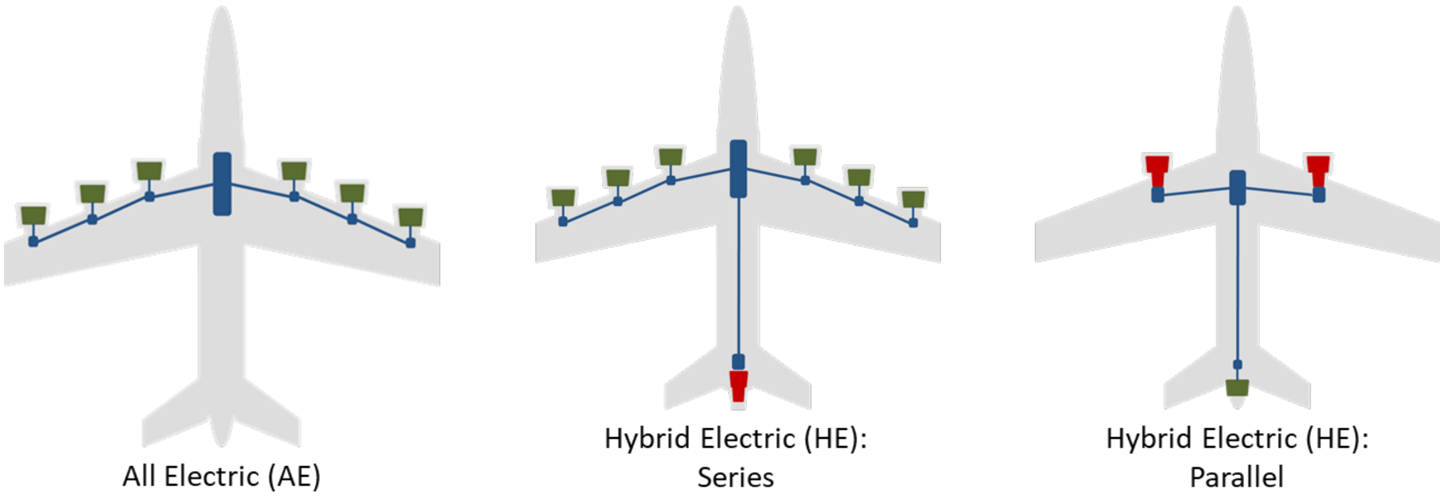
Image courtesy of Volocopter

POWER AND PROPULSION

ELECTRIC FLIGHT TECHNOLOGY: LAUNCHING THE FUTURE OF AEROSPACE ENGINEERING

The growth of electric propulsion for aviation is driven mainly by its ability to mitigate the environmental impact of hydrocarbon-burning aircraft, both from the perspective of gas emissions and that of noise. The cost of operation would also be lower, but since that will be offset by the higher acquisition cost, it is not clear whether the overall cost of ownership of an electric aircraft would be lower than that of a conventional aircraft. Electric aircraft are projected to be more efficient – nearly 20% more, according to some studies – which is clearly a good portent, when we consider the fact that we are talking about a nonrenewable resource like jet fuel. Innovations in the oil and gas industry like shale oil and fracking have helped extend the end-date for hydrocarbon fuels; and cars, buses, and even trucks are incorporating electric or hybrid-electric propulsion systems, reducing the pressure on hydrocarbons even further. Another benefit from this shift to electric propulsion is that it has resulted in lowering the costs of electrical components such as motors, power electronics, and batteries that are essential to this technology. The economies of scale engendered by the automotive industry will help contain costs in the aviation sector as well, even though the unique regulatory constraints on commercial aviation do limit the gains we can achieve from the economies of scale. Still, in many ways, this is the ideal time for electric propulsion to experience a real and sustained growth. Business trends are just as important as



DIFFERENT ELECTRIC PROPULSION ARCHITECTURE

technology trends in helping this growth. New business models involving electric aircraft, such as autonomous air-taxi services, are providing the financial incentives for companies to invest in this mode of transportation. These are all plausible explanations for the rapid growth in the development of electric propulsion; but the real reason for this growth probably has more to do with the zeitgeist of our times than anything else. The automotive sector has embraced electric propulsion in a big way as has the unmanned aerial vehicle (UAV) sector. This is having an impact on the aviation sector as well. For aviation, however, the technology associated with electric propulsion still has a long way to go before it would make financial sense.

History of Electric Propulsion

Electric propulsion is not a new phenomenon; its history goes back many decades—stretching back, indeed, to the beginning of flight. Lighter-than-air balloons were propelled by electrically driven props late in the nineteenth century. However, it is only recently that electric propulsion has taken off in a concrete manner with a possible commercial future. Major research organizations such as NASA and airframers like Airbus have helped develop and demonstrate electric aircraft, but even more critically, smaller companies in the general aviation (GA) sector are doing more than their bit to push this technology forward.

In 1973 the first heavier-than-air electric aircraft, powered solely by a battery, successfully demonstrated sustained flight, albeit for less than a quarter-hour. This was accomplished in Linz, Austria, by a modified motor-glider, the Brditschka MBE1. The focus then shifted to solar-powered aircraft, and the field of electric aircraft was dominated by these for the next several decades. While solar power is an important means of generating electric energy, an aircraft powered solely by solar panels is not very practical, because the surface area needed to generate enough electricity to be able to lift a decent amount of payload is way too large.

Take for example the Solar Impulse 2, which completed the circumnavigation of the world in 2016. However, solar power is not a very viable solution for transportation because of the very low efficiency of the cells themselves. Even though the Solar Impulse aircraft has a wingspan the size of a Boeing B-747 jumbo, it only has enough power to carry one pilot, while the Boeing jumbo jet can carry more than 400 passengers!

Since the beginning of this century, progress in more practical all-electric (AE) and hybrid-electric (HE) vehicles has accelerated; mainly in the GA area. This is the aviation sector that consists of commercial aircraft that (usually) carry less than 20 passengers and are not used for scheduled passenger service. Electric propulsion is also predominant in the unmanned aircraft sector both for remote-controlled airplanes and for autonomous vehicles. Because these aircraft are relatively lightweight, batteries have proven to be quite viable as power sources. One of the most popular vehicles these days is the quadcopter (a remote-controlled four-rotor vertical-lift aircraft) that is being used for recreational and professional activities such as videography.

Electrically powered GA aircraft that can accommodate two to four passengers are being considered for air-taxi services. In addition to electric propulsion, most of these aircraft will be designed to operate autonomously. Ultimately this would mean that taxi service would be provided by a vertical takeoff and landing (VTOL) aircraft that does not have a pilot, but will be able to carry passengers from point to point, flying as far and for as long as its batteries will allow in a safe and reliable manner. The VTOL Volocopter 2X from Germany, which is not yet fully autonomous, will probably become the first aircraft to demonstrate such a service in Dubai later in 2017. There are several other programs, many from small startup companies, working towards this goal. It is clear that in one form or another, an air-taxi service will be operational soon.

In the larger aircraft sector, slated for the commercial airline market, the emphasis is on HE designs, because AE designs are not technically feasible today. Here the idea is to use a gas turbine as a primary source of power that generates electricity which in turn feeds a battery and one or more electric motors. The motors drive propellers or ducted fans. Electric energy can either be the sole provider of propulsive power for an aircraft or it can be coupled with a different source of energy such as hydrogen, solar power, and a hydrocarbon fuel. Here the traditional engine would drive generators to provide electrical power. If all the energy of the engine goes into providing electric power which then drives the electric motors and the fans, then this would be termed a series HE architecture. If the engine provides thrust in addition to electric power, then it would be a parallel HE architecture. In the included Figure, electric motors are shown in green and the traditional engines are depicted in red. In the HE architectures the battery (blue) need or need not be present, but most designs employ it. NASA is working with many companies including Boeing to study such designs. In support of this effort it is building a laboratory in Ohio to test out very high powered electric components and powertrains. Airbus and Rolls-Royce have teamed up in Europe to develop their own concept of an HE aircraft. This e-Thrust plane employs a series HE architecture with superconductive electric components to increase system efficiency.

While these architectures refer to purely electric energy being used directly for propulsion, the use of electric energy to power various aircraft subsystems has grown steadily over the years. In this more-electric (ME) architecture many mechanical or hydromechanical functions are increasingly being provided by electrical components. In the GA category, this trend is less evident, but even here we have started to see more electric components being introduced.

The ME category is becoming more prevalent, even in large commercial aircraft. A case in point is the Boeing B787, which has a number of electrically driven components. Transport aircraft were traditionally designed with major hydraulic and pneumatic actuation systems. The design of Boeing 787, however, was a major departure from those conventional systems, as evidenced by the extensive use of electricity to power systems. Airbus has not followed suit quite to the same extent, with their latest A350 aircraft being much less ambitious in its reach towards a more electrically powered philosophy.

Electrical Components

Regardless of the architecture of the electric propulsion system, to achieve an AE or an HE propulsion system, two elements are necessary: At one end, we need a source for the electric energy, and at the other, a set of systems that use this energy. The fundamental electrical components of an electric aircraft are essentially the same as those in a conventional tube-and-wing aircraft. They are just designed to be more compact, more efficient, and more powerful. As the primary aim of an electric aircraft is to get the maximum work out of a limited resource, that is, increase the overall system efficiency, much research has concentrated on working on component efficiencies. Many new and innovative approaches have been considered at the component level as well as at the system level. For example, in addition to trying to improve standard designs, researchers have been looking at developing components that can work at much lower temperatures, that is, in a cryogenically cooled system. As is well known, electric conduction becomes much more efficient at lower temperatures in many metals. This can be exploited to make systems that deliver the same power with a much lighter and more compact design.

The main source of electric power on an HE aircraft are the generators and on an AE aircraft it is a bank of battery cells. Aircraft power is transmitted via appropriate buses to components that use this power. While current aircraft use high voltage AC busses to transfer power to high power loads, in the future it is not clear whether that will continue to be the case. High power DC lines are also being considered. NASA has set up the NASA Electric Aircraft Testbed (NEAT) to test and validate various architectures. On the other end, the biggest loads are obviously the motors that drive the fans generating thrust. Additional load is provided by actuators and batteries, and all the other necessary electric functions on the aircraft. For electric propulsion to be commercially viable the power or energy density of various components need to increase, as will be discussed below.

Electric propulsion allows the source and the sink of power to be physically separated and distributed, with the ability for designers to use several propulsors instead of two or four as is true of current designs. By integrating the entire airframe with a distributed propulsion system, we can possibly take care of flight control using just the differential thrust on the propulsors, instead of control surfaces. In the future, this capability could allow designers to eliminate some control surfaces, thereby saving weight.

Future Trends

Electric motors were propelling lighter-than-air aircraft at the very beginning of the aviation era, but electric propulsion never became a dominant technology. That honor has been held by the hydrocarbon molecule ever since the Wright brothers changed the world of aviation on a cold December day on a beach in North Carolina in 1903. Jet fuel will continue to be the mainstay of aviation in the foreseeable future, but the prospects for electric flight are changing in a hurry as increasing numbers of individuals and companies are developing and flying electric aircraft. The range of vehicles spans from small personal hovercrafts to large twin-aisle passenger aircraft. Electric Propulsion Technology is clearly a rapidly evolving area of research, with new ideas and results being reported every day and in every field.

The lack of electric storage devices with sufficiently high energy density is one of the main reasons electric propulsion is being held back. This is true of land vehicles as much as it is of aircraft. However, technological progress is being made in this area. Researchers are working on new developments in rechargeable battery technology, and the hope is that by 2035 the energy densities associated with these batteries will grow from 200 to 1,000 Wh/kg. This will only be possible if radical new chemistries are invented and productized. There is still a long way to go compared to hydrocarbons, which have specific energies higher than 10,000 Wh/kg. Nevertheless, such a five-fold increase would do wonders for the range and weight of an AE vehicle. The cost of these rechargeable batteries has been falling dramatically as well—falling by almost an order of magnitude in the past decade—in no small measure because of the tremendous demand that the automotive industry is generating. With the expansion of the giga-factory that Tesla is operating in Nevada, the cost is expected to come down further. At least one company (Eviation) is considering using primary (nonrechargeable) batteries along with secondary batteries to make certification of AE aircraft easier. Primary batteries can be used for reserve power, which is hopefully never tapped into.

Additionally, power densities of the major loads on the aircraft are increasing. Current motors and generators operate at about 5 kW/kg and these are planned to rise to more than 13 kW/kg. Power electronics are at around 13 kW/kg with a target of around 20 kW/kg. With these kinds of power and energy densities, AE air-taxi service will be financially viable.

Researchers active in this industry have envisioned that by 2050 there will be a vehicle that looks like a wing with cleverly concealed holes across its surface housing the fans, no (or minimal) flight control surfaces, supercooled PEs, generators, and motors, battery storage technology that is five to seven times better than what is available today, having vertical or short takeoff and landing capabilities, and that has the ability to carry as many passengers as the twin-aisle wide-bodies today. The stated goals of most of these programs are reduced noise, emissions, and fuel burn, by as much as 75% over current numbers. Given the state of the art and the rate at which technological progress is being made, it is clear that the goals of reducing emissions and noise will be easier to achieve than that of reducing fuel burn.

Adapted from *Electric Flight Technology: The Unfolding of a New Future*, by R. Rajamani, 2018, Warrendale, PA: SAE International. Adapted with permission.