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Electric aircraft

An **electric aircraft** is an aircraft powered by electric motors. Electricity may be supplied by a variety of methods including batteries, ground power cables, solar cells, ultracapacitors, fuel cells and power beaming.^[1]

Small, electrically powered model aircraft have been flown since the 1970s, with one unconfirmed report as early as 1957.^{[2][3]} They have since developed into small unmanned aerial vehicles (UAV) or drones, which in the twenty-first century have become widely used for many purposes.

Although manned flights in a tethered helicopter go back to 1917 and in airships to the previous century, the first manned free flight by an electrically powered aeroplane, the MB-E1, was not made until October 1973 and most manned electric aircraft today are still only experimental demonstrators.^[4] Between 2015 and 2016, Solar Impulse 2 completed a circumnavigation of the Earth using solar power.^[5] More recently, interest in electric passenger aircraft has grown, for both commercial airliners and personal air vehicles.



In 2016, *Solar Impulse 2* was the first solar-powered aircraft to complete circumnavigation of the world.

Contents

Design

- Batteries
- Power cables
- Solar cells
- Ultracapacitors
- Fuel cells
- Microwaves

History

- Pioneers
- First prototypes
- Unmanned aerial vehicles
- Light aircraft
- Solar Impulse circumnavigation
- Developments
- Hybrid power

Ion wind

Applications

Electric rotorcraft

Unmanned

Manned

Projects

See also

References

External links

Design

All electric aircraft to date have been powered by electric motors driving thrust-generating propellers or lift-generating rotors.^[6] Some of the propeller-driven types have been airships.

Mechanisms for storing and supplying the necessary electricity vary considerably, and each has distinct advantages and disadvantages. Mechanisms used include:

- Batteries can retain a significant electrical charge, although their weight still limits the range achievable.
- Power cables connect to a ground-based supply.
- Solar cells convert sunlight directly into electricity.
- Ultracapacitors can store a limited amount of energy for short bursts of high-power use
- Fuel cells are similar to batteries but draw their reactants from an external source.
- Microwave energy has been beamed from a ground-based source.

Batteries

Batteries are the most common energy carrier component of electric aircraft, due to their relatively high capacity. Batteries were the earliest source of electricity, first powering airships in the nineteenth century. These early batteries were very heavy and it was not until the arrival of technologies such as nickel-cadmium (NiCd) rechargeable types in the second half of the twentieth century, that batteries became a practicable power source. Modern battery types include lithium-based and a number of other less widely used technologies.^[7] Such batteries remain a popular power source today, although they still have limited endurance between charges and hence limited range.

Batteries are also often used for temporary storage of electricity generated by another source.

Power cables

An electrical power cable may be connected to a ground-based supply, such as an electric generator. At low altitudes this can avoid carrying heavy batteries and was used by the experimental Petróczy-Kármán-Žurovec PKZ-1 observation helicopter of 1917. However such a craft must remain tethered to a ground facility, and the higher and or farther it flies, the heavier the weight of cable it must lift with it.

Solar cells

A solar cell converts sunlight directly into electricity, either for direct power or temporary storage. The power output of solar cells is small, even when many are connected together, which limits their use and is also expensive. However their use of freely available sunlight makes them attractive for high-altitude, long-endurance applications.

For endurance flights, keeping the craft in the air all night typically requires a backup storage system, which supplies power during the hours of darkness and recharges during the day.

Ultracapacitors

An ultracapacitor can store a limited amount of energy for short bursts of high-power use, such as when taking off, but due to its relatively small storage ability it is not suitable as a primary power source. Its advantage over a small battery is the ability to charge and discharge much faster with higher peak currents.

Fuel cells

A fuel cell uses the reaction between two fluids such as hydrogen and oxygen to create electricity. Unlike a battery, the fluids are not stored in the battery but are drawn in from outside. This offers the prospect of much greater range than batteries and experimental examples have flown, but the technology has yet to reach production.

Microwaves

Power beaming of electromagnetic energy such as microwaves, like a power cable, requires a ground-based power source. However, compared to a power cable, power beaming carries much less weight penalty as altitude increases. The technology has been demonstrated on small models but awaits practical development.^[1]

History

Pioneers

The use of electricity for aircraft propulsion was first experimented with during the development of the airship which took place in the latter part of the nineteenth century. On 8 October 1883, Gaston Tissandier flew the first electrically-powered airship.^{[8]:292} The following year, Charles Renard and Arthur Krebs flew La France with a more powerful motor.^{[8]:306} Even with the lifting capacity of an airship, the heavy accumulators needed to store the electricity severely limited the speed and range of such early airships.

For a tethered device such as an air observation platform, it is possible to run the power up the tether. In an attempt to create a more practical solution than the clumsy balloons then in use, the Austro-Hungarian Petróczy-Kármán-Žurovec PKZ-1 electric-powered helicopter was flown in 1917. It had a specially-designed 190 hp (140 kW) continuous-rated electric motor made by Austro-Daimler and received its power up a cable from a ground-based DC generator. However electric motors were not yet powerful enough for such applications and the motor burned out after only a few flights.^[9]

In 1909, an electric free flight model was claimed to have been flown eight minutes, but this claim was disputed by the builder of the first recorded electric Radio-Controlled model aircraft flight in 1957.^[10] Power density for electric flight is problematic even for small models.

In 1964, William C. Brown at Raytheon flew a model helicopter that received all of the power needed for flight by microwave power transmission.^[11]

First prototypes

Success in a full-sized aeroplane would not be achieved until Nickel-cadmium (NiCad) batteries were developed, having a much higher storage-to-weight ratio than older technologies. In 1973, Fred Militky and Heino Brditschka converted a Brditschka HB-3 motor glider to an electric aircraft, the Militky MB-E1. On 21 October, it flew for just 14 minutes to become the first manned electric aircraft to fly under its own power.^{[4][12]}

Developed almost in parallel with NiCad technology, solar cells were also slowly becoming a practicable power source. Following a successful model test in 1974, the world's first official flight in a solar-powered, man-carrying aircraft took place on April 29, 1979. The Mauro Solar Riser used photovoltaic cells to deliver 350 watts at 30 volts. These charged a small battery, which in turn powered the motor. The battery alone was capable of powering the motor for 3 to 5 minutes, following a 1.5-hour charge, enabling it to reach a gliding altitude.^[13]

Under the direction of Freddie To, an architect and member of the Kremer prize committee, the Solar One was designed by David Williams and produced by Solar-Powered Aircraft Developments. A motor-glider type aircraft originally built as a pedal-powered airplane to attempt the Channel crossing, the airplane proved too heavy to be successfully powered by human power and was then

converted to solar power,^[14] using an electric motor driven by batteries that were charged before flight by a solar cell array on the wing.^[15] The maiden flight of Solar One took place at Lasham Airfield, Hampshire, on June 13, 1979.^[16]

Following successful human-powered flight, a relaunched Kremer prize allowed the crew to store energy before takeoff.^[17] In the 1980s several such designs stored electricity generated by pedalling, including the Massachusetts Institute of Technology Monarch and the Aerovironment Bionic Bat.^[18]

The human piloted Solair 1, developed by Günther Rochelt, flew in 1983 with notably improved performance.^{[2][19]} It employed 2499 wing-mounted solar cells.^[2]

The German solar-powered aircraft "Icaré II" was designed and built by the institute of aircraft design (Institut für Flugzeugbau) of the University of Stuttgart in 1996. The leader of the project and often pilot of the aircraft is Rudolf Voit-Nitschmann the head of the institute. The design won the Berblinger prize in 1996, the EAA Special Achievement Award in Oshkosh, the Golden Daidalos Medal of the German Aeroclub and the OSTIV-Prize in France in 1997.^[20]

Unmanned aerial vehicles

NASA's Pathfinder, Pathfinder Plus, Centurion, and Helios were a series of solar and fuel cell system–powered unmanned aerial vehicles (UAVs) developed by AeroVironment, Inc. from 1983 until 2003 under NASA's Environmental Research Aircraft and Sensor Technology program.^{[21][22]} On September 11, 1995, Pathfinder set an unofficial altitude record for solar-powered aircraft of 50,000 feet (15,000 m) during a 12-hour flight from NASA Dryden.^[21] After further modifications, the aircraft was moved to the U.S. Navy's Pacific Missile Range Facility (PMRF) on the Hawaiian island of Kauai. On July 7, 1997, Pathfinder raised the altitude record for solar–powered aircraft to 71,530 feet (21,800 m), which was also the record for propeller–driven aircraft.^[21]

The NASA Pathfinder Plus electric-powered unmanned aerial vehicle

On August 6, 1998, Pathfinder Plus raised the national altitude record to 80,201 feet (24,445 m) for solar-powered and propeller-driven aircraft.^{[21][23]}

On August 14, 2001 Helios set an altitude record of 96,863 feet (29,524 m) – the record for FAI class U (experimental/new technologies), and FAI class U-1.d (remotely controlled UAV: mass 500 kg to less than 2,500 kg) as well as the altitude record for propeller–driven aircraft.^[24] On June 26, 2003, the Helios prototype broke up and fell into the Pacific Ocean off Hawaii after the aircraft encountered turbulence, ending the program.

The QinetiQ Zephyr is a lightweight solar-powered unmanned aerial vehicle (UAV). As of 23 July 2010 it holds the endurance record for an unmanned aerial vehicle of over 2 weeks (336 hours).^[25] It is of carbon fiber-reinforced polymer construction, the 2010 version weighing 50 kg (110 lb)^[26] (the 2008 version weighed 30 kg (66 lb)) with a span of 22.5 metres^[26] (the 2008 version had 18 metres (59 feet)). During the day it uses sunlight to charge lithium-sulphur batteries, which power the aircraft at night.^[27] In July 2010 a Zephyr made a world record UAV endurance flight of 336 hours, 22 minutes and 8 seconds (more than two weeks) and also set an altitude record of 70,742 feet (21,562 m) for FAI class U-1.c (remotely controlled UAV: weight 50 kg to less than 500 kg).^{[28][29][30]}

Light aircraft

The first commercially available, non-certified production electric aircraft, the Alisport Silent Club self-launching glider plane, flew in 1997. It is optionally driven by a 13 kW (17 hp) DC electric motor running on 40 kg (88 lb) of batteries that store 1.4 kWh of energy.^[31]

The first certificate of airworthiness for an electric powered aircraft was granted to the Lange Antares 20E in 2003. Also an electric, self-launching 20-meter glider/sailplane, with a 42-kilowatt DC/DC brushless motor and lithium-ion batteries, it can climb up to 3,000 meters with fully charged cells.^[32] The first flight was in 2003. In 2011 the aircraft won the 2011 Berblinger competition.^[33]

In 2005, Alan Cocconi of AC Propulsion flew, with the assistance of several other pilots, an unmanned airplane named "SoLong" for 48 hours non-stop, propelled entirely by solar energy. This was the first such around-the-clock flight, on energy stored in the batteries mounted on the plane.^{[34][35]}

In 2007, the non-profit CAFE Foundation held the first Electric Aircraft Symposium in San Francisco.^[36]

The Boeing-led FCD (fuel cell demonstrator) project uses a Diamond HK-36 Super Dimona motor glider as a research test bed for a hydrogen fuel cell powered light airplane.^[37] Successful flights took place in February and March 2008.^{[37][38]}

The first the NASA Green Flight Challenge took place in 2011 and was won by a Pipistrel Taurus G4 on 3 October 2011.^{[39][40][41]}

In 2008, The Boeing Fuel Cell Demonstrator

In 2013 Chip Yates demonstrated that the world's fastest electric plane, a Long ESA, a modified Rutan Long-EZ, could outperform a gasoline-powered Cessna and other aircraft in a series of trials verified by the Fédération Aéronautique Internationale. The Long ESA was found to be less expensive, have a higher maximum speed, and higher rate of climb, partly due to the ability of the aircraft to maintain performance at altitude as no combustion takes place.^{[42][43]}

In 2017, Siemens used a modified Extra EA-300 acrobatic airplane, the 330LE, to set two new records: on March 23 at the Dinslaken Schwarze Heide airfield in Germany, the aircraft reached a top speed of around 340 km/h (180 kn) over three kilometers; the next day, it became the first glider towing electric aircraft.^[44]

Solar Impulse circumnavigation

Solar Impulse 2 is powered by four electric motors. Energy from solar cells on the wings and horizontal stabilizer is stored in lithium polymer batteries and used to drive propellers.^{[45][46]} In 2012 the first Solar Impulse made the first intercontinental flight by a solar plane, flying from Madrid, Spain to Rabat, Morocco.^{[47][48]}

Completed in 2014, Solar Impulse 2 carried more solar cells and more powerful engines, among other improvements. In March 2015, the plane took off on the first stage of a planned round-the-world trip, flying eastwards from Abu Dhabi, United Arab Emirates.^[5] Due to battery damage, the craft halted at Hawaii, where its batteries were replaced. It resumed the circumnavigation in April 2016^[49] and reached Seville, Spain, in June 2016.^[50] The following month it returned to Abu Dhabi, completing its circumnavigation of the world.^[51]

Developments

The NASA Puffin was a concept, proposed in 2010, for an electric-powered, vertical takeoff and landing (VTOL), personal air vehicle.^[52]

The European Commission has financed many low TRL projects for innovative electric or hybrid propulsion aircraft. The ENFICA-FC is a project of the European Commission, to study and demonstrate an all-electric aircraft with fuel-cells as the main or auxiliary power system. During the three-year project, a fuel-cell based power system was designed and flown in a Rapid 200FC ultralight aircraft.^[53]

The NASA Electric Aircraft Testbed (NEAT) is a NASA reconfigurable testbed in Plum Brook Station, Ohio, used to design, develop, assemble and test electric aircraft power systems, from a small, one or two person aircraft up to 20 MW (27,000 hp) airliners.^[54] NASA research agreements (NRA) are granted to develop electric-propulsion components. They will be completed in 2019 and the internal NASA work by 2020, then they will be assembled in a megawatt-scale drive system to be tested in the narrowbody-sized NEAT.^[55]

NASA Electric Aircraft Testbed

NASA developed the X-57 Maxwell from a Tecnam P2006T

NASA developed the X-57 Maxwell to demonstrate technology to reduce fuel use, emissions, and noise.^[56] Modified from a Tecnam P2006T, the X-57 will have 14 electric motors driving propellers mounted on the wing leading edges.^[57] In July 2017, Scaled Composites is modifying a first P2006T by replacing the piston engines with electric motors, to fly early in 2018, then will move the motors to the wingtips to increase propulsive efficiency and finally will instal of the high aspect ratio wing with 12 smaller props.^[58]

In September 2017, UK budget carrier EasyJet announced it was developing an electric 180-seater for 2027 with Wright Electric.^[59] Founded in 2016, US Wright Electric built a two-seat proof-of-concept with 272 kg (600 lb) of batteries, and believes they can be scaled up with substantially lighter new battery chemistries: a 291 nm (540 km) range would suffice for 20% of Easyjet passengers.^[60] Wright Electric will then develop a 10-seater, eventually an at least 120 passengers single aisle, short haul airliner and targets 50% lower noise and 10% lower costs.^[61] Jeffrey Engler, CEO of Wright Electric, estimates that commercially viable electric planes will lead to around a 30% reduction in energy costs.^[62]

On March 19, 2018, Israel Aerospace Industries announced it plans to develop a short-haul electric airliner, building on its small UAS electric power systems experience. It could develop it in-house, or with a startup like Israeli Eviation, U.S. Zunum Aero or Wright Electric.^[63]

Australia-based MagniX intends to fly an electric Cessna 208 Caravan with a 540 kW (720 hp) motor for up to an hour, by August 2019. The company's Magni5 electric motor already produces continuously 265–300 kW (355–402 hp) peak at 2,500 rpm at 95% efficiency with a 53 kg (117 lb.) dry mass, a 5 kW/kg power density, competing with the 260 kW (350 hp), 50 kg (110 lb) Siemens SP260D for the Extra 330LE.^[64] By September 2018, a 350 hp (260 kW) electric motor with a propeller had been tested on a Cessna iron bird. The 750 hp (560 kW) Caravan was expected to fly by the fall of 2019 and by 2022 MagniX estimates electric aircraft will fly up to 500 and 1,000 mi (800 and 1,610 km) by 2024.^[65] The motor ran on a test dynamometer for 1,000 hours. The iron bird is a Caravan forward fuselage used as a test bed, with the usual PT6 turboprop engine replaced by an electric motor, inverter and a liquid-cooling system, including radiators, driving a Cessna 206 propeller. The production motor will produce 280 kW (380 hp) at 1,900 rpm, down from the test motor's 2,500 rpm, allowing the installation of the propeller without a reduction gearbox.^[66]

A 560-kW (750-hp) MagniX electric motor was installed in a de Havilland Canada DHC-2 Beaver seaplane. Harbour Air, based in British Columbia, hopes to introduce the aircraft in commercial service in 2021, for trips under 30 minutes initially, until range increases with battery technology.^[67] On December 10, 2019, it made its first flight of four minutes duration, from the Fraser River near Vancouver. The normally-fitted Pratt & Whitney R-985 Wasp Junior piston engine of the six-passenger Beaver was replaced by a 135 kg (297 lb) magni500, with swappable batteries, allowing 30 minute flights plus 30 minutes of reserve power.^[68]

By May 2019, Roland Berger counted almost 170 electric aircraft programmes in development, anticipating over 200 by the year end, with a majority of them aimed at the urban air taxi role.^[69] US/UK startup ZeroAvia develops zero-emissions fuel-cell propulsion systems for small aircraft, and

tests its HyFlyer in Orkney supported by £2.7 million from the UK government. A demonstrator for the German Scylax E10 10-seater should fly in 2022, it should be used by FLN Frisia Luftverkehr to connect East Frisian islands with its 300 km (160 nmi) range and 300 m (980 ft) short takeoff and landing distance.^[67]

Hybrid power

A hybrid electric aircraft is an aircraft with a hybrid electric powertrain, needed for airliners as the energy density of lithium-ion batteries is much lower than aviation fuel. By May 2018, there were over 30 projects, and short-haul hybrid-electric airliners were envisioned from 2032. The most advanced are the Zunum Aero 10-seater, the Airbus E-Fan X demonstrator, the VoltAero Cassio, UTC is modifying a Bombardier Dash 8, while an Ampaire prototype first flew on 6 June 2019.

Ion wind

In November 2018, MIT engineers flew the first plane with no moving parts, propelled by ion wind thrust.^{[70][71]}

Applications

Currently, battery-powered electric aircraft have much more limited payload, range and endurance than those powered by internal combustion engines. It is hence only suitable for small aircraft (for large passenger aircraft, an improvement of the energy density by a factor 20 compared to li-ion batteries would be required^[72]). However, pilot training is an area that emphasises short flights. Several companies make, or have demonstrated, light aircraft suitable for initial flight training. The Airbus E-Fan was aimed at flight training but the project was cancelled. Pipistrel makes light sport electric aircraft such as the Pipistrel WATTsUP. A prototype of the Aero Electric Sun Flyer. The advantage of electric aircraft for flight training is the lower cost of electrical energy compared to aviation fuel. Noise and exhaust emissions are also reduced compared with combustion engines.

Electric rotorcraft

Although the Austro-Hungarian Petróczy-Kármán-Žurovec team flew an experimental tethered military observation helicopter in 1917, the use of electric power for rotor-borne flight was not exploited until modern times.

Unmanned

Lightweight components have enabled the development, for recreational purposes among others, of small, cheap radio-controlled unmanned aerial vehicles, often called drones, notably the widespread quadcopter.

Manned

The Solution F/Chretien Helicopter the world's first man-carrying, free-flying electric helicopter was developed by Pascal Chretien. The concept was taken from the conceptual computer-aided design model on September 10, 2010 to the first testing at 30% power on March 1, 2011—less than six months. The aircraft first flew August 4 to 12, 2011. All development was conducted in Venelles, France.^{[73][74]}

Solution F/Chretien helicopter

In February 2016, Philippe Antoine, AQUINEA and ENAC, Ecole Nationale Supérieure de l'Aviation Civile, successfully flew the first full electric conventional helicopter called Volta in Castelnaudary Airfield, France. Volta demonstrated a 15-minute hovering flight in December 2016. The helicopter is powered by two PMSM motors delivering together 80 kW and a 22kWh Lithium battery. Volta is officially registered by DGAC, the French Airworthiness Authority, and is authorized for flying in the French civilian airspace.

In September 2016, Martine Rothblatt and Tier1 Engineering successfully tested an electric-powered helicopter. The five minute flight reached an altitude of 400 feet with a peak speed of 80 knots. The Robinson R44 helicopter was modified with two three-phase permanent magnet synchronous YASA Motors, weighing 100 lb, plus 11 Brammo Lithium polymer batteries weighing 1100 lb and a digital cockpit display.^{[75][76][77]} It later flew for 20 minutes in 2016.^{[78][79]}

Projects

The Sikorsky Firefly S-300 was a project to flight test an electric rotorcraft, but the project was put on hold due to battery limitations.^[80] The world's first large-scale all-electric tilt-rotor was the AgustaWestland Project Zero unmanned aerial vehicle technology demonstrator, which performed unmanned tethered flights on ground power in June 2011, less than six months after the company gave the official go-ahead.^[81]

The Airbus CityAirbus is an electrically-powered VTOL aircraft demonstrator. The multirotor aircraft is intended to carry four passengers, with a pilot initially and to become self-piloted when regulations allow.^[82] Its first unmanned flight is scheduled for the end of 2018 with manned flights following in 2019.^[83] Type certification and commercial introduction are planned for 2023.^[84]

See also

- Electric vehicle
- Emerging aviation fuels
- Energy density
- Hydrogen-powered aircraft

- [Nuclear-powered aircraft](#)
- [Ion wind](#)
- [List of electric aircraft](#)
- [Radio-controlled aircraft](#)
- [Solar energy](#)

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