Electric Aviation Development and Future Prospect

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Abstract. Electric vehicles have gained significant traction, with hybrid and fully electric cars and trucks increasingly replacing traditional fuel-powered vehicles. However, the development of electrified aircraft has received comparatively less public attention. This research study aims to explore the evolution of electric aviation and its future potential. It delves into the history of electric aviation and examines various types of electric propulsion systems, including all-electric, series hybrid, parallel hybrid, and turboelectric configurations. The study also analyzes the advantages and disadvantages of current electrified aircraft technologies. Additionally, it considers the policies and investments necessary to stimulate the advancement of electric aviation. As concerns over environmental issues and energy shortages grow, electrified aircraft could emerge as a viable alternative to gas turbine aircraft, offering reduced carbon emissions and lower operational costs. The purpose of this paper is to provide a comprehensive overview of the current state and future prospects of electric aviation, with a particular emphasis on its potential to revolutionize the aviation industry.

1 Introduction

The electrification of aircraft began much earlier than most people expected on the 12th of Oct 1973. The inaugural flight of an electric-powered aircraft occurred in Wels, Austria, the Militky-Brditschka Elektroflieger No.1. The flight lasted approximately nine minutes and reached an altitude of approximately 300 meters [1] (Fig. 1). However, after MB-E1, the development of electrified aircraft stagnated. Thirty years later, some companies realized the value of the electrification of aircraft, and development started again. The electrification of vehicles is more environmentally friendly and efficient, and carbon emissions and toxic gas emissions can also be reduced significantly. At the same time, electric vehicles follow the trend of environmental protection and the public's perception of some inevitable defects of traditional fuel carriers. Thus, using electrified vehicles to replace traditional fuel vehicles has become one of the most viable options. As the battery and charging technology improved enormously, lots of electric vehicles entered the market to replace traditional fuel vehicles [1].

Similar to electrified vehicles on the ground, electric machines for aircraft have different types of architectures, including all-electric, hybrid-electric, and turboelectric [2]. All of

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these structures have their advantages and disadvantages in different aspects of aircraft. At the same time, some barriers are still hard to overcome, like the weight of electric components and battery packs. This research provides insight into the architecture of the electrification of aircraft and the prospect of electrified aircraft.

Fig. 1. MB-E1 (Militky-Brditschka Elektroflieger No.1) [1].

2 Different architectures of electric machines

In turbine engines, the turbine's speed and the propeller's rotational speed are linked. [3]. This coupling is a barrier to thermal efficiency, so electrified vehicles are used to overcome this defect and improve overall thermal efficiency. The fan and turbine speeds in direct current systems are disconnected, allowing each to be run at its optimal operating section. [3]. Similar to internal combustion engine vehicles and their electrification, electric machines for aircraft have full-electric and hybrid architecture. This is because the energy contained in the battery is much smaller than energy in the same volume of fuel. Thus, the hybrid electric machine is designed to reduce weight and have a higher thermal efficiency compared to gas turbine and all-electric architecture. All these electric machine architectures can be classified into four types: all-electric, series hybrid, parallel hybrid, and turboelectric [2]. In this research study, all these architectures will be introduced from the perspective of structures and advantages.

2.1 All-electric architecture

Fig. 2 shows the full-electric architecture. Full-electric architecture is expected to be the most economical and viable choice to reduce carbon emission and toxic gas release for both fixed-wing aircraft and vertical take-off and landing aircraft [2]. Aircraft (plural) have to carry a battery, and the battery's weight is the main problem all-electric aircraft have. Batteries store less energy in the same volume compared with fuel, so aircraft using this architecture always have a relatively short range. After the battery generates current, the current goes through the converter to the motor, and then one or more propellers will rotate to produce force for taking off and flying. For flight, mission ranges that are less than 600 nautical miles, NOx emissions at the take-off area can be remarkably reduced by 40%, and direct CO_2 emissions can be reduced by 15% [2]. In short, all-electric architecture is the most environmentally friendly structure, as the battery-specific energy increases can be used in a wider working environment.

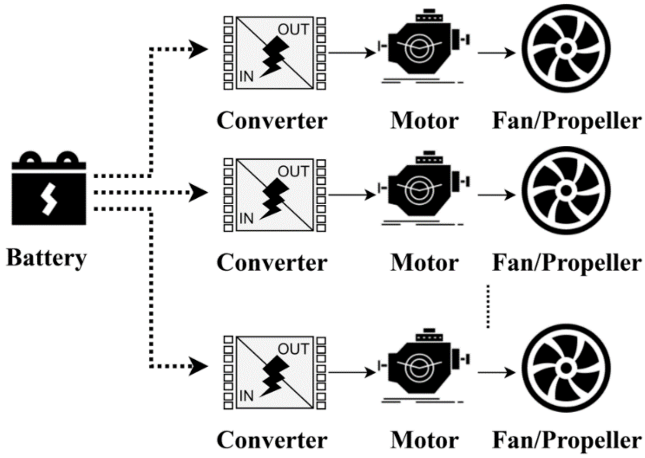

Fig. 2. All-electric architecture [2].

2.2 Serious hybrid electric architecture

The configuration of the series hybrid electric architecture is illustrated in Fig. 3, and it uses a single gas turbine to generate electricity, and electricity is stored in the battery on the aircraft [2]. Then, it is the same as all-electric architecture. The motors drive some small propellers. Either an energy storage device or a generator powered by a gas turbine provides the electrical power. With this configuration, the transmission system and electrical conversion enable the gas turbine system to separate from the propulsors [4]. The ability to run the gas turbine independently of propeller speed is a built-in advantage of the serious hybrid electric architecture [4]. The thermal efficiency of the gas turbine can reach its maximum efficiency because the power transmission system and the electric power generation system are separated [2]. Hybrid electric architecture can store the electric energy in a battery to supplement the propulsive power in different operational segments [4]. Compared with all-electric aircraft, hybrid architecture uses fuel as a source of energy. Because of the higher fuel energy capacity, aircraft can store a small battery. Thus, serious hybrid aircraft can be lighter and have a longer flight range.

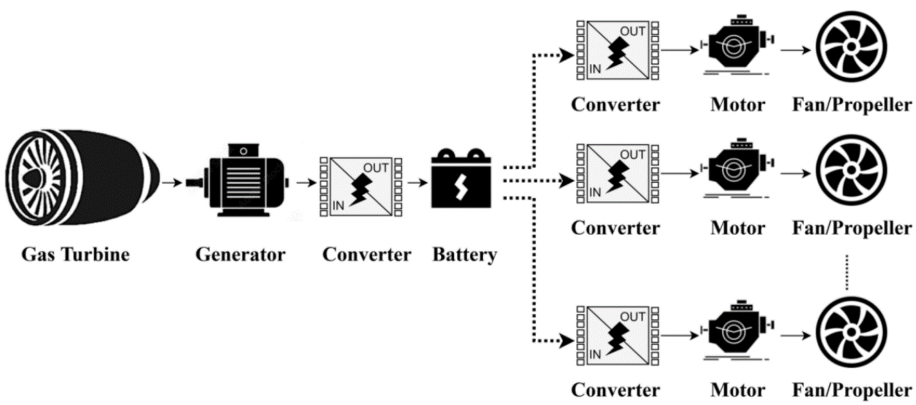

Fig. 3. Serious hybrid electric architecture [2].

2.3 Parallel hybrid electric architecture

As shown in Fig. 4, in the parallel hybrid electric architecture, gas turbines are connected parallelly to produce electricity and store it in the battery. Both motors and gas turbines are stored on a shaft to drive the propeller [2]. Low-pressure and high-pressure shafts can the electric power boost both on-take [2]. Compared with serious hybrid electric architecture, the parallel structure has fewer electric components, so it will save weight and space for the aircraft [2]. This is a significant advantage for the aircraft, and it will make the flight more economically competitive.

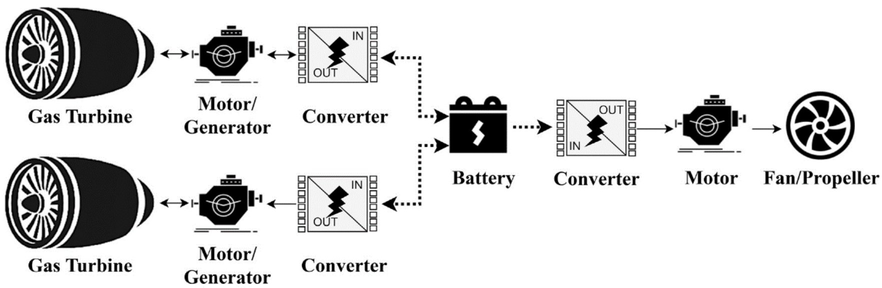

Fig. 4. Parallel hybrid electric architecture [2].

2.4 Turboelectric architecture

As illustrated in Fig. 5, the turboelectric configuration comprises a gas turbine that drives a generator, thereby producing electricity for each motor. The electricity is transmitted to the individual motors and subsequently drives the propellers [2]. An electricity storage package is not included in this configuration, and turboelectric aircraft use fuel as their only energy resource. This structure is the most promising architecture because it does not relate to the battery energy storage technology [2]. In addition, the volume of electric components it needs is smaller due to the movement of the battery pack. Thus, it can also reduce weight to have better flight economy efficiency.

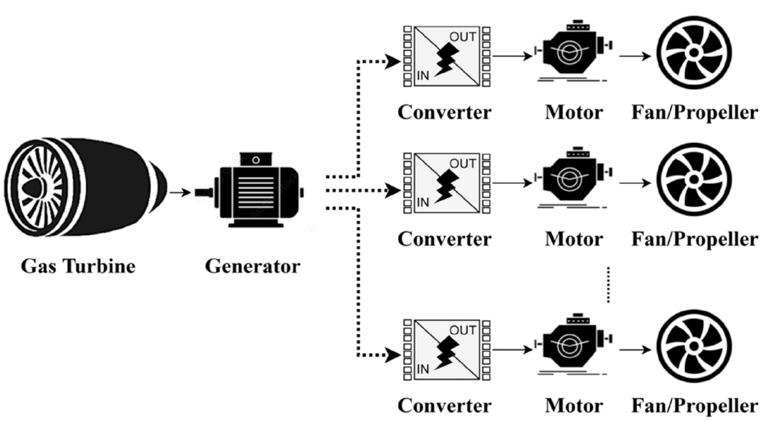

Fig. 5. Turboelectric architecture [2].

3 Merits and demerits of electrified aircraft compared with gas turbine aircraft

3.1 Advantages

3.1.1 Thermal efficiency

Electrified aircraft have a higher thermal efficiency compared with gas turbine aircraft. Electric machines are necessary for all electrified aircraft, and researchers are trying to build up a lightweight, high-efficiency electric machine [5]. The large airliner needs megawatt-level components because they can be synchronously stored in different architectures like turboelectric and hybrid electric [5]. Smaller aircraft can use hybrid electric and turboelectric propulsion systems, whereas single-aisle airplanes can use a combination of both forms of propulsion. [5].

NASA is sponsoring Ohio State University and the University of Illinois to develop megawatt-class motors, and their efficiency goal of the electric machines is all over 95% [5]. However, the production process of electricity has some energy loss, so the thermal efficiency of electricity production is about 65%. This needs to be considered when this research is calculating the electric machine's total thermal efficiency. In comparison, research from the National Academies Press states that turbine thermodynamic efficiencies of no more than 55% and propulsive efficiencies of approximately 70% define the most efficient airplane gas turbines in use or under development in the past ten years [6]. From the product of two efficiencies, these gas turbine aircraft have an overall efficiency of about 40% [6]. Gas turbine aircraft cannot always work in a zone with the highest thermal efficiency, but electric machines can. The aggregate efficiency of the electric machine, defined as the product of the electric machine's thermal efficiency and the efficiency of electricity production, is markedly superior to the thermodynamic efficiency of the gas turbine.

3.1.2 Pollution

Reducing carbon emissions and meeting the trend of environmental protection are the main reasons why electrified aircraft have developed. The two principal forms of air pollution emitted by gas turbines are smoke and nitrogen oxides at maximum speed and unburned fuel and carbon monoxide at idle working conditions [7]. Traces of smoke are a visual nuisance, and the other pollutants are either toxic, irritating, or both [7].

Electric machines have almost no pollution when they are working compared with gas turbines; the only pollution electric machines have is from the carbon emission when electricity is produced and the used battery package. However, more and more companies have launched their battery recycling plan because some materials in the battery are still valuable–for example, lithium, cobalt, manganese, and nickel cells [8]. In this way, recycling batteries will greatly reduce the impact on the plant-growing environment due to toxic chemicals in the batteries. At the same time, firms can reduce the cost of materials to increase their profit and develop sustainably.

3.2 Disadvantages

3.2.1 Convenience

Lots of private gas turbine aircraft use different designs to reduce drug force, and the goal of these designs is to have better flight performance. To be more specific, some private aircraft can even fly cross-ocean airlines, and they have an outstanding maximum cruise speed and maximum altitude. As shown in Fig. 6, G650 from Gulfstream has a maximum flight range of 7000 nautical miles, about 13000 km. This range is enough to have non-stop flights from

Europe to North America, Europe to Africa, or Europe to much of Asia. At the same time, the G650 has a long-range cruise speed of 488 knots and a maximum cruise speed of 516 knots. It also has a maximum cruising altitude of 51,000 feet, which is placed at the joint top of the list for the highest private jet cruising altitudes. All these satisfying flight performances are because fuel has a high energy capacity.

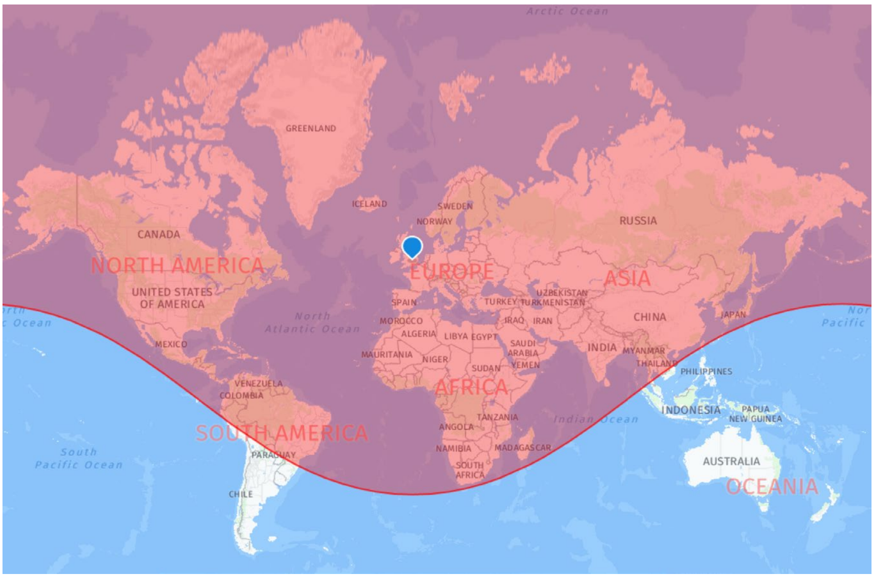

Fig. 6. Non-stop flight range of G650 take off from London, reproduced from the website: https://compareprivateplanes.com/listing/large/g650#performance.

Electrified aircraft have heavy battery packs and electrical components, so their weight is heavier than gas turbine aircraft with similar carrying capacity. Electrified aircraft Eviation Alice was first developed in Israel and is powered by two electric motor machines. It can carry 9 passengers and 2 pilots, similar to the passenger carrying capacity of G650. Nevertheless, it has a relatively small non-stop flight range and low cruising velocity compared to the G650. The flight range of Eviation Alice is only 460 km, about 4% of the maximum range of G650, and a maximum velocity of 260 knots.

Another problem is that electrified aircraft need to be changed, and the energy charging efficiency is very slow. For Eviation Alice, 30 minutes of charging time is required for each hour flight. This problem is another problem passengers will consider when they are planning for their flight.

3.2.2 Safety

Safety is always put in the first place for both passengers and an aircraft company. Compared with mature fuel gas turbine technology and structure. Therefore, if electrified aircraft want to be widely accepted by the public, electrified aircraft companies still need to solve potential safety hazards. One of the potential risks is the battery pack, which contains a huge amount of energy and is very unstable. Concurrently, the rechargeable Li-ion battery technology has reached a sufficient level of maturity, and the charge and discharge rates of these batteries have also been enhanced [9].

On the other hand, the incidence of safety related issues has also increased as battery performance improved and adoption enhanced [9]. The onset of overheating, heat accumulation and gas release process, and combustion and explosion are the thermal runaway has three stages [9]. The best solution to control the accident rate is to minimize the incidence of manufacturing defects [9].

4 Future prospect

Electrified vehicles are the main method of transportation in the foreseeable future. Many global organizations and governments are promoting the electrification industry, including the electrified aircraft manufacturing industry.

4.1 Global policies about electrified aircraft

The International Civil Aviation Organization, ICAO, officially launched the "ICAO Assistance, Capacity-building and Training for Sustainable Aviation Fuels (ACT-SAF) program" on 1st June 2022 [10]. ICAO aims to showcase what ICAO has achieved and continues to strive for in decarbonizing aviation [10]. Governments also expect to boost the employment rate and develop the economy through the development of new electrified aircraft industries, and they hope to stimulate technological development through release conditions for electric machine engines. On 27 September 2021, the Federal Aviation Administration (FAA) published Special Conditions for Electric Engine Airworthiness [11]. This was a special condition that was imposed on the first project for the certification of an electric motor. The condition represents a huge step forward in the commercial process [11].

4.2 Commercial value

The considerable quantity of energy necessary to transport hundreds of passengers over distances of hundreds or thousands of miles represents a significant challenge for the use of battery energy storage in commercial transportation. The disparity in energy density between batteries and hydrocarbon fuels implies that the range of an electrified aircraft will be considerably diminished in comparison to an equivalent aircraft powered by a gas turbine. [12]. Therefore, short-range commercial flights for Urban Air Mobility make it easier to achieve results in stages [12]. A number of companies have an outstanding performance in the commercial development of electrified aircraft. They have secured significant investments, built factories and developed new technologies in line with future market conditions. Archer is a company located in the U.S. It will provide short-range flights, which are called electric air taxis [13]. Archer received a supplementary investment of $55 million from Stellantis in accordance with the terms of their strategic funding agreement. This was subsequent to the attainment of the transition flight test milestone by Archer in the preceding month. [13]. Through this transaction, we can see the market's optimistic judgment on the development of electrified flying machines.

5 Conclusion

To sum up, the research concludes the different architectures of electric machines and summarizes the pros and cons of electrified aircraft. The existing advantages and disadvantages of electrified vehicles reveal that there are many barriers if electrified vehicles are going to be commercially available and have flying performance that completely exceeds that of conventional gas turbine aircraft. This is mainly due to the weight and size of the battery packs, which can severely reduce the range, cruise speed and carrying ability of the aircraft.

Fortunately, growing environmental concerns from the public are stimulating development and investment in the field of high-performance battery packs. As a result, technology in this area is developing at an extremely fast pace. In the future, there is a high probability that the battery energy capacity limit can be broken with the development in the field of materials science. Driven by Governments and the market, electrified aircraft will complete their commercialization and eventually replace gas-turbine aircraft in most situations. At the same time, electrified vehicles will also create new markets, such as cheap short-range flights, and continue to attract more investment.

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