

The research status and technical situation of electric aircraft

Lu Liu

School of Mechanical Engineering, Tongji University, Shanghai, 201804, China

2051187@tongji.edu.cn

Abstract. Against the backdrop of escalating global carbon emissions, the emergence of electric aircraft has provided a promising avenue for addressing this pressing challenge. This article discusses the development background, definition, classification, and successful trial cases of electric aircraft, and summarizes the advantages of electric aircraft compared with traditional fossil fuel aircraft. Electric aircraft can be classified into different categories based on several factors, including their power system, purposes, and passenger-carrying capabilities. These classifications help in understanding the diverse range of electric aircraft designs and their suitability for specific purposes. And it has the advantages of emission reduction and noise reduction, economic comfort, high efficiency and reliability, which will have a positive impact on the construction of the new urban transportation system in the future. And then this article introduces the current technological development status from three aspects: electric propulsion system, body material and battery. As an environmentally friendly, efficient and sustainable aviation transportation solution, electric aircraft are receiving more and more attention and research.

Keywords: electric aircraft, propulsion system, technical situation.

1. Introduction

The greenhouse effect and global warming are serious problems due to increasing carbon dioxide. The objective, therefore, becomes sustainable development, which corresponds to current needs without jeopardizing the potential of coming generations [1]. It is necessary to strike a balance between social welfare, environmental protection, and economic progress.

The current global carbon emissions situation is highly critical, with some regions and sectors making progress but overall facing challenges. Despite various nations taking action in energy conservation and emissions reduction, there is still much work to be done to achieve global emission reduction targets, particularly in reducing carbon dioxide (CO₂) emissions.

Energy production and consumption are the primary sources of carbon emissions worldwide. The combustion of coal, oil, and natural gas releases substantial amounts of CO₂, making them major contributors to greenhouse gas emissions. Other significant sources of emissions include industrial processes, transportation, and agriculture, among which the aviation sector is a significant contributor to global greenhouse gas emissions.

The aviation industry exhibits relatively high levels of CO₂ emissions. According to statistics, carbon emissions caused by aviation account for 2% of the total carbon emissions produced by humans. The combustion process in aircraft engines generates a considerable amount of CO₂, which is released into

the atmosphere. With the growth of the global aviation industry and an increase in the number of flights, CO₂ emissions from the aviation sector continue to rise. Additionally, aviation emissions belong to the category of high-intensity emissions, meaning they produce a higher amount of CO₂ per unit of energy compared to other sectors. This is due to the high energy density of aviation fuel, resulting in a relatively higher CO₂ output during combustion. Moreover, CO₂ is a persistent greenhouse gas that can remain in the atmosphere for decades or even longer. The impact of CO₂ emissions from the aviation sector on global climate change is cumulative over the long term.

An electric aircraft is defined as an aircraft that is powered by electricity and utilizes an electric propulsion system, such as batteries, fuel cells, or other electric devices, to generate thrust and enable flight. The development and research of electric aircraft aim to revolutionize the aerospace industry by introducing cleaner and more energy-efficient alternatives to traditional fossil fuel-powered aircraft.

Compared to conventional fuel-powered aircraft, electric aircraft offer several advantages. Firstly, environmental sustainability: Electric aircraft are driven by clean energy sources such as batteries or fuel cells, resulting in reduced emissions of CO₂ and other harmful gases. This is significant in terms of mitigating climate change, improving air quality, and protecting the environment. Secondly, energy efficiency and operational cost reduction: Electric aircraft have higher energy utilization efficiency, leading to lower energy consumption compared to conventional fuel-powered aircraft. Additionally, the maintenance costs of electric aircraft are relatively lower as the electric systems are simpler with fewer mechanical components [2], eliminating the need for regular fuel and lubricant replacements, among others. Moreover, with advancements in battery technology and cost reduction, the feasibility and reliability of electric aircraft are gradually increasing. Improved battery capacity and charging technology enable electric aircraft to achieve longer ranges and faster charging speeds. Thirdly, electric aircraft exhibit lower levels of noise and vibration compared to conventional fuel-powered aircraft, which positively impacts reducing noise pollution in the surrounding environment and for residents. This makes electric aircraft more suitable for operations in urban areas and noise-sensitive regions.

Electric aircraft can be categorized using various classification criteria. Based on Power Source, they can be divided into pure electric aircraft and hybrid electric aircraft. Pure electric aircraft is an aircraft that rely solely on batteries or other electrical storage devices for propulsion. Hybrid electric aircraft is an aircraft that combines electric power with other power sources, such as fuel cells or generators. For the purpose, they can be divided into light sports electric aircraft, urban air electric aircraft, short-distance transport electric aircraft, large commercial aircraft, etc. [3]. In terms of passenger-carrying capabilities, they also can be divided into single, small and large electric aircraft.

2. Successful cases of electric aircraft trial flight

Electric aircraft development has made significant progress over the past few decades, achieving not only technological breakthroughs but also successful flight testing. Here are some examples of successful flight-testing cases.

In 1973, a German man called Fred Militky converted an Austrian-made glider into a nickel-cadmium battery electric aircraft MB-E1 for a 12-minute manned flight [4]. On December 23, 2007, France successfully conducted the inaugural flight of Electra, the world's first electrically powered light aircraft [5]. This marked a significant milestone as it became the pioneering conventional aircraft with wing-mounted fixed propulsion, utilizing lightweight lithium polymer batteries as its energy source. Subsequently, on December 9, 2008, ElectraFlyer-C, developed by an American electric aircraft company, underwent its maiden test flight. Powered by lithium batteries, this aircraft demonstrated the capability to fly quietly at a speed of 112 km/h for 1.5 to 2 hours, with a remarkable maximum speed of 144 km/h. In 2009, the world's first glider "DLR-H2" powered by a hydrogen fuel cell was successfully tested in Germany. Notably, in December 2010, France achieved a breakthrough by setting a new flight speed record for electric aircraft. The dual-engine aircraft, Cricri90, attained an impressive velocity of 261 km/h, surpassing all previous benchmarks. Building upon these achievements, in July 2012, the United States made a significant contribution to the field with the successful test flight of Long-ESA, a fully electric aircraft. Demonstrating exceptional performance, it shattered the previous electric aircraft's

flight record by achieving a level flight speed of 326 km/h, thus establishing itself as the fastest fully electric aircraft of that era. In July 2015, The technology verification machine “E-Fan” which is a pure electric two-seat airbus successfully flew over the English Channel [6]. In 2015-2016, Solar Impulse 2 Sun Energy Flying Aircraft passed the intermittent ten segment of the route to complete the global flying. In September 2015, The technology verification machine “E-Fan” which is a pure electric two-seat airbus successfully flew over the English Channel. Continuing the advancements, on October 28, 2019, China accomplished a significant milestone by successfully conducting the maiden flight of Rx4E, the country's first domestically developed four-seater electric aircraft. This breakthrough occurred at Shenyang Caihu Airport in Liaoning Province, marking a pivotal moment for China's independent research and development in this field [5].

Lastly, on December 10, 2019, the world witnessed the historic inaugural flight of the first-ever fully electric commercial aircraft. Taking off from Vancouver, Canada, this momentous event marked a major stride in the progression of electric aviation [5].

3. Electric propulsion technology

Traditional aircraft generate power by converting the chemical energy of fuel into mechanical energy through engines. In contrast, electric propulsion aircraft directly convert electrical energy into mechanical energy using electric motors. The electric propulsion system has the potential to significantly improve energy efficiency.

The energy efficiency of electric propulsion systems can exceed 70%, which is much higher than the approximately 40% efficiency of traditional turbofan engines. This implies that adopting electric propulsion technology has the potential to enhance overall system efficiency. By directly converting electrical energy into mechanical energy, electric propulsion aircraft reduce energy losses associated with intermediate energy conversions, thereby increasing energy utilization efficiency.

Due to the high efficiency of electric propulsion systems, electric aircraft achieve lower energy consumption and emissions. By reducing or eliminating fuel combustion processes, electric propulsion aircraft can decrease carbon dioxide and other harmful gas emissions, leading to a reduced environmental impact. This aligns with global efforts to reduce carbon emissions and achieve sustainable aviation.

The electric propulsion system consists of several key components. The propulsion system provides the necessary thrust and includes devices such as ducted fans, propellers, or other propulsion mechanisms. The power supply system delivers electrical energy to the propulsion system and other aircraft systems. Additionally, auxiliary systems such as energy storage systems and protection systems are required to support the electric propulsion system.

In summary, electric propulsion systems in aircraft offer significant advantages in terms of energy efficiency, reduced fuel consumption, and lower emissions. They represent a promising pathway towards sustainable aviation. The successful implementation of electric propulsion systems relies on the development of robust and efficient power supply systems, energy storage systems, and protection systems.

3.1. Electric propulsion systems

The propulsion system, which directly generates power for electric propulsion aircraft, is the core component of the aircraft and mainly consists of the power generation device and the drive motor system. The power generation device is typically a propeller or a ducted fan [7]. The propulsion system utilizes electric motors as the power source, providing greater design flexibility and control compared to traditional engines. The electric motor can be designed in a direct-drive configuration, eliminating the need for gear mechanisms, simplifying the structure of the propulsion system, and enhancing its reliability [8]. Alternatively, a high-speed motor with a gearbox solution can be employed to reduce the weight of the motor system.

3.2. Power supply system

The power supply system in an electric aircraft is responsible for providing the required electrical energy to the propulsion system and other aircraft systems. The power supply system consists of battery packs, power management systems, and distribution systems. The battery packs are crucial components for storing electrical energy, with commonly used options being high-energy-density lithium-ion batteries. The power management system controls the distribution and management of electrical energy to ensure stable operation and optimal performance of the system. The distribution system allocates electrical energy to various systems and devices, ensuring an effective power supply.

3.3. Energy storage system

The energy storage system plays a role in storing and releasing electrical energy in electric aircraft. Lithium-ion batteries are currently one of the most commonly used energy storage devices due to their high energy density, long lifespan, and fast charging capabilities. With technological advancements, new energy storage technologies such as solid-state batteries are also being continuously researched and explored. The design of the energy storage system needs to consider battery capacity, weight, and safety to meet the range and performance requirements of electric aircraft.

3.4. Protection system

The protection system plays a critical role in ensuring the safe operation of electric aircraft. It includes various monitoring and protection devices to monitor battery status, temperature, current, voltage, and other parameters, taking appropriate measures to protect the batteries and other systems from overloads, overheating, and other potential faults. The protection system also includes fire detection and fire suppression systems to handle potential fire risks. The design of the protection system needs to consider flight safety, reliability, and performance to ensure the normal operation of electric aircraft.

When researching and developing the propulsion system, power supply system, energy storage system, and protection system for electric aircraft, various factors need to be considered, including energy efficiency, reliability, safety, weight, cost, and environmental impact. With continuous technological progress and innovation, these systems will continue to be improved and optimized, driving the development of electric aviation and achieving more efficient, sustainable, and environmentally friendly electric flight.

4. Body technology

Modern electric aircraft employ a range of techniques in the fuselage structure to meet the demands of performance, safety, and comfort. Previously, aluminum was commonly used as the shell material for electric aircraft due to its lightweight and rigidity. However, in recent years, with the advancement of carbon fiber reinforced polymer (CFRP) technology and the reduction in costs, CFRP has been increasingly applied in the aviation industry. Although the specific timeline may vary depending on the aircraft model and manufacturer, since 2010, CFRP has gradually become the preferred choice for the fuselage material of electric aircraft, driven by the increasing demand for lightweight and high-performance materials. Its exceptional strength, stiffness, and lightweight properties make it an ideal choice for meeting the requirements of electric aircraft.

Carbon fiber is not only stronger than steel and lighter than aluminum, but it also offers the versatility of being molded into various complex shapes, reducing the overall number of parts required. The benefits of CFRP extend beyond its mechanical strength and weight savings; it also plays a pivotal role in reducing fuel costs and enhancing aerodynamic performance. Carbon fibers have the highest maximum service temperature up to 2000 centigrade and have a specific strength only lower than ultra-high molecular weight polyethylene.

In electric aircraft, CFRP finds extensive application in critical components such as wings, keel beams, tail cones, frames, and doors. These parts are subjected to demanding operating conditions and must withstand high pressure and low temperatures. The superior strength-to-weight ratio of CFRP enables it to endure these challenges effectively. The pursuit of fuel efficiency and operational efficacy

has always driven the aerospace industry to address the core challenge of reducing airframe mass. CFRP's remarkable properties make it a pivotal contributor to achieving this objective.

The international landscape of fibrous materials and CFRP highlights the undeniable advantage of this composite material. The future trajectory of CFRP development revolves around three main aspects: high performance, low cost, and multifunctionality. Industry demands call for CFRP to exhibit not only light weight but also exceptional wear resistance, corrosion resistance, low-temperature tolerance, high-temperature stability, and oxidation resistance [9]. Furthermore, the focus extends to the development of low-cost production technologies encompassing raw materials, composite processes, and quality control. Advanced composite materials are progressively advancing from simple structural roles to the integration of structure and function, aligning with the direction of multifunctional development.

Overall, CFRP's prominence in the aviation industry, combined with ongoing research and innovation, ensures its continued evolution as a critical material for enhancing aircraft performance, fuel efficiency, and structural integrity. The pursuit of high-performance, cost-effective, and multifunctional CFRP materials remains a focal point for future advancements in the field of aviation.

5. Battery technology

The electric power system of electric aircraft has made significant advancements and progress in recent years. With the continuous evolution of advanced battery technologies such as lithium-ion batteries and solid-state batteries, the energy storage capacity of electric aircraft has been significantly enhanced. These advanced batteries not only possess high energy density but also offer longer lifespans and faster charging capabilities, enabling electric aircraft to achieve extended range and quicker charging speeds.

Lead-acid batteries have widespread applications and mature technologies in electric aircraft. Lead-acid batteries are cost-effective, possess longer cycle life, and exhibit stable performance, making them a reliable and economical choice. However, their energy density is relatively low, limiting the achievable flight range compared to lithium-sulfur batteries.

In comparison, the lithium-sulfur (Li-S) battery has gained significant attention in the field of electric aviation in recent years. Its unique characteristics make it well-suited for this particular application. Firstly, the Li-S battery exhibits exceptional energy density. Compared to conventional lithium-ion batteries and lead-acid batteries, the Li-S battery can store more energy, enabling longer flight ranges for electric aircraft. They exhibit a highly attractive feature of having a two-electron redox reaction, which gives both electrodes a high theoretical capacity. Additionally, lithium-sulfur batteries are associated with a significantly higher theoretical energy density of 2600 Wh/kg, surpassing the theoretical capacity of lithium cobalt oxide batteries. Even their practical energy density can be 2-3 times higher than that of the most advanced commercial lithium-ion batteries currently available [10]. In 2014, the specific energy of lithium-sulfur batteries developed by OXIS Corporation reached 300 Wh/kg. Furthermore, the natural abundance and non-toxicity of sulfur provide lithium-sulfur batteries with cost advantages and better environmental friendliness compared to lithium-ion batteries. This is of utmost importance for electric aviation, as high energy density batteries are crucial for providing sufficient power [11]. Secondly, the Li-S battery offers a lower weight profile. Weight reduction is a critical factor in electric aircraft design due to the sensitivity of aircraft to weight. The Li-S battery, with its higher energy storage capacity per unit weight, contributes to reducing the overall weight of the aircraft, thereby enhancing its performance and efficiency. However, the lightweight characteristics of lithium sulfur batteries may also lead to some structural and security problems, which need to be considered and solved in design and manufacturing. Furthermore, the Li-S battery demonstrates high charging rates. The charging time of electric aircraft plays a vital role in improving operational efficiency. The Li-S battery exhibits fast charging capabilities, allowing for quicker power restoration, reduced charging times, and increased aircraft availability. Nevertheless, to guarantee its dependability and stability, lithium sulfur batteries' charging performance and cycle life still need to be significantly enhanced.

In summary, as one of the power systems for electric aircraft, lithium-sulfur batteries still face some challenges in terms of their application maturity and performance. For instance, its stability at high

temperatures is relatively poor, and issues related to capacity decay and cycle life may arise. Further research and technological advancements are required to address these challenges, ensuring the reliability and durability of Li-S batteries in electric aircraft applications.

Another highly promising system is the sodium-sulfur battery. In electric aircraft, both lithium-sulfur batteries and sodium-sulfur batteries are extensively studied and explored as energy storage technologies [12]. Currently, sodium-sulfur batteries typically have an energy density ranging from 100 to 200 Wh/kg, while lithium-sulfur batteries can achieve an energy density of 200 to 300 Wh/kg. They both offer the advantages of high energy density and longer flight range and possess environmentally friendly and sustainable characteristics [13].

However, lithium-sulfur batteries and sodium-sulfur batteries differ in certain key aspects. Lithium-sulfur batteries have higher energy density and lighter weight, which potentially gives them an advantage in electric aircraft. They also have lower costs and higher charging efficiency, although their performance may be limited in high-temperature environments. On the other hand, sodium-sulfur batteries perform better under high-temperature conditions and exhibit higher cycle life and improved safety performance. However, sodium-sulfur batteries have relatively lower energy density and larger size and weight, which may impact the performance and payload capacity of electric aircraft. Therefore, the choice between lithium-sulfur batteries and sodium-sulfur batteries depends on specific application requirements and trade-offs. Further research and development to enhance the performance and reliability of these battery technologies, as well as addressing their challenges and limitations, will contribute to better determining their optimal use in the field of electric aircraft.

In conclusion, as one of the power systems for electric aircraft, lithium-sulfur batteries still face some challenges in terms of their application maturity and performance. Despite the potential of lithium-sulfur batteries to become a key energy storage technology for future electric aircraft, further research and development efforts are required to enhance their energy density, safety, and cycle life, and to address their limitations in high temperature and structural aspects.

6. Conclusion

This article provides an overview of the current carbon emissions in the aviation industry and analyzes the types and definitions of electric aircraft. It examines the development status of electric aircraft through successful test flight cases. The article primarily focuses on several technical aspects of electric aircraft: electric propulsion technology, body technology and battery technology. Electric aircraft, as an environmentally friendly, efficient, and sustainable solution for aviation transportation, holds broad prospects for development. Although electric aircraft has significant advantages in energy saving, environmental protection and other fields, considering its technical level, manufacturing cost, propulsion mode, flight speed, take-off weight and many other limitations, its current application fields are mostly focused on short-distance feeder transportation and unmanned aerial vehicle (UAV) field. For a considerable period of time in the foreseeable future, both civil and military aviation sectors will continue to rely on traditional aero-engines as their primary power source. However, given the increasing scarcity of conventional fossil fuels and the growing concerns about environmental pollution, the development and application of clean alternative fuels for aviation and driving the transformation of aircraft will become an important development trend.

References

- [1] Benegas Jayme, Diego, 2019. Evaluation of the Hybrid-Electric Aircraft Project Airbus E-Fan X. Master Thesis. Hamburg University of Applied Sciences, Aircraft Design and Systems Group (AERO). Available from: <https://nbn-resolving.org/urn:nbn:de:gbv:18302-aero2019-06-30.012> [viewed 2023-06-17].
- [2] Li K. 2019 Aviation Science and Technology, 30 (1): 1-7.
- [3] Yin L, Wu C. 2019 Auto World Vehicle Engineering Technology, 21: 57-59.
- [4] Huang R, Fang Z. 2021 Caixin Weekly, 37: 58-61.
- [5] Woodste. 2020 Energy saving, 39 (4): 57-60.

- [6] Liu H. 2023 China Equipment Engineering 7: 248-251.
- [7] Zhao C, et al. 2012 Science and Technology Herald 30.12: 62-70.
- [8] Kong X, Zhang Z, Lu J, et al. 2018 Aviation Journal, 39 (1): 51-67.
- [9] Lionetto, F. 2021 Materials,14, 19.
- [10] Li H. 2020 The preparation of positive and negative pole materials of alkaline metal batteries and the study of battery structure design and performance research. Jilin University.
- [11] Jiao T, Tong, Li,et al. 2023 CIESC Journal, 74(1): 170-191.
- [12] Li S, Song Y, Bian Y, et al. 2023 Energy storage science and technology,5: 1315-1331.
- [13] Chan C, 1993 An overview of electric vehicle technology, in Proceedings of the IEEE, vol. 8, p. 1202-1213.