

Electric Aviation: Pioneering the Future through Advances in Electric Vehicle Technologies

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Abstract. This paper explores the technological advancements in electric vehicles (EVs) and their potential applications in electric aviation. Core EV technologies such as battery systems, electric motors, and electronic control systems are analyzed to understand their relevance to aviation. The evolution of various battery types, including lithium-ion, solid-state, and next-generation alternatives, is emphasized, focusing on their critical role in addressing energy density challenges that electric aircraft will face. Additionally, this paper discusses the technical, regulatory, and manufacturing hurdles that must be overcome for electric aviation to become commercially viable. From battery weight and endurance limitations to energy-efficient propulsion systems, the complexities of translating EV innovations to aviation are assessed. The paper concludes by examining future possibilities for electric aviation, highlighting how breakthroughs in EV technology could lead to sustainable air travel. Through this lens, the technological trajectory of EVs provides key insights into the opportunities and challenges of developing electric aircraft.

Keywords: Battery; electric motor; electric vehicle; electric aviation.

1. Introduction

In the past hundred years, fuel vehicles have been widely used as one of the main ways of travel, but the two main problems have not been substantially solved in the century-old replacement. One is that internal combustion engines are inefficient and cannot make full use of the energy they consume. For example, the efficiency of the "180 TURBO" of the Dongfeng brand is less than 10 % (total fuel tank 47 L, total displacement 1.498 L) [1]. The other is the exhaust gases produced by internal combustion engines, some of which are toxic, such as nitrogen oxides. Others are some of the main gases that contribute to global warming, such as carbon dioxide. So, the emergence of electric vehicles (EVs) in recent years can be a good solution to these two problems. The auto giant Audi introduced the advantages of its EVS on environmental protection: their company will reach the goal of carbon neutrality by 2050 [2]. This is the significance of EVs for their current existence and further development. Everything also has two sides. The reason why the development of EVs is also very important is because the current advantages and disadvantages of EVs are very prominent. The biggest advantage is that compared with traditional fuel vehicles, EVs can greatly reduce pollution and improve energy efficiency. For the disadvantages, the biggest problem of EVs is that they cannot operate in some low-temperature environments, such as lithium-ion power batteries in low-temperature conditions, the performance of the battery deteriorates, affecting the vehicle's power and driving range, and the battery temperature is below 0 °C cannot be charged [3]. This is also why research and development of battery technology and battery materials need to continue. These technologies play a decisive role in the development of new EVs.

Similarly, as one of several commonly used means of transportation, the aircraft is also likely to be electronic in the future; theoretically, as long as the battery carried by the aircraft has enough electricity and output power, then it is possible to make electricity become the main energy source for aircraft operation. In fact, many aircraft manufacturers are already working on electronic aircraft. So, in general, the most important thing is the battery, and only when the battery can meet the power needs of some devices can the design of cutting-edge electronics and put into use, not just in planes and cars.

2. The Core Technology of EVs

2.1. Battery Technology

Battery technology is one of the most important components of the EVs which is responsible for the energy supply of the entire vehicle. As one of the most important characteristics of electronic vehicles, compared with traditional fuel vehicles, the advantages of lead batteries are more obvious, and the application of its technology in EVs has more significant comparative advantages and better prospects in the market. In fact, similar to winding lead-acid batteries that have been widely used in hybrid EVs in Europe and the United States, such batteries of Bolder company in the United States in accordance with the simulated charge and discharge mode of hybrid EVs ($\Delta\text{SOC} = 1.25\%$), the cycle life of the battery can reach 100,000 times, and the deep cycle life can reach 600 times. The shelf life at 25 °C is expected to be 6-8 years [4]. This shows that new lead-acid battery technology is developing in the direction of extending battery life. Another company, Hawker's 36 V/8 Ah bipolar lug wound valve-controlled lead batteries, which have been tested well on Honda Insight HEV, use a variety of new processes, such as rolled thin plate (0.4 mm), non-curing internalized formation, and high assembly pressure. The 8 Ah battery can discharge at A high rate of 250 A, and its specific power and other performance have reached the level of the hydrogen-nickel battery, and the cost is less than 1/2 of the hydrogen-nickel battery [4]. This proves that the new lead-acid battery technology can greatly reduce the cost while improving the battery discharge efficiency. In addition to the above two new lead-battery technologies, super batteries, lead-carbon batteries, bipolar ceramic diaphragm batteries and other new technologies of lead-acid batteries have been introduced or industrialized. These new lead-acid batteries have the opportunity to increase the energy density and battery life to a large extent and have a great contribution to the future manufacturing of EVs.

2.2. Electric Motor

As one of the main components of the EV braking system, the number and parameters of the electric motor have an important impact on the power output, driving range and overall performance of the EVs. The number of electric motors directly affects the power output of EVs. The power output of pure EVs mainly relies on electric motors to convert electrical energy into kinetic energy to drive the car forward. At present, the EV motors that are being applied or developed are mainly DC motors, induction motors, permanent magnet brushless motors and switched reluctance motors [5]. At present, some advanced motor technology has been put into the manufacturing of EVs, such as the switched reluctance motor, the switched reluctance motor (SRM) developed by France's FIAT company and China's second Automobile Factory has been put into practical application in EVs: switched reluctance motor has been used in all-electric buses. SRM is a brushless motor without any form of rotor conductor and permanent magnet, and the concentrated stator windings and pulsed current allow its power converter to adopt a more reliable form of circuit topology. Its advantages are also very prominent, with simple and reliable, efficient operation in a wide speed and torque range, flexible control, four-quadrant operation, fast response speed, and low-cost advantages [5]. The assurance of motor efficiency can improve some speed-related functions of EVs, such as reducing the 100-meter acceleration time and the maximum speed that can be achieved.

2.3. Electric Control

In addition to the battery that provides energy and the motor that outputs energy, the electrical control system that generally controls the operation of the EVs is also one of the important components of the EVs. It generally includes traction motors, motor drivers, controllers and various sensors, mechanical deceleration and transmission devices, wheels and so on [6]. Electric control and drive systems of EVs also have many functions to achieve, such as the need to control the start and stop of the motor, accurately adjust the speed and torque output of the motor, detect and manage the charge and discharge of the EVs battery, and timely intervene in potential dangers such as overcharge, over-discharge and overheating of the battery. In addition, the driving force and braking force of the

wheels can be adjusted to maintain the overall stability of the car, and part of the kinetic energy is converted into electrical energy stored in the car battery when the car brakes. It is for the consideration of vehicle smoothness that the latest electronically controlled electric four-wheel steering system improves the handling stability of the car at high speed and flexibility when driving at low speed or turning, mainly applied to high-end cars. The stepper motor offers several advantages. Its angular displacement is directly proportional to the number of input pulses, allowing for precise control. It also delivers excellent servo performance and, when combined with angle feedback, can form a high-performance closed-loop CNC system.

Additionally, the motor boasts a fast dynamic response, enabling quick start-stop actions, reversible rotation, and variable speed. It can self-lock and maintain torque, ensuring stability during operation. With a simple, robust design, it is durable and highly resistant to interference, making it suitable for various demanding applications [7].

3. Batteries for EVs

3.1. Lithium-Ion Battery

The lithium-ion battery is one of the most commonly used battery types for EVs. Its main materials include positive electrode materials (commonly used lithium cobalt oxide, lithium manganese oxide, lithium iron phosphate), negative electrode materials (commonly used graphite or silicon composite materials, with good cycling performance), electrolyte (lithium ion in the conduction medium between the positive and negative electrodes, Commonly used lithium hexafluorophosphate, lithium difluorophosphate and organic solvent carbonate, ether) and other parts. The positive electrode material not only participates in the chemical reaction of the battery as an electrode material but also is the main source of lithium ions, which has the greatest impact on improving the energy density and cost structure of lithium-ion batteries. Lithium cobaltate cathode material is widely used in smartphone and tablet batteries, but it is not suitable for car batteries due to cost and safety concerns. For negative electrode materials and graphite, which is most commonly used for negative electrode materials, it is characterized by stable performance, low cost and long life. The disadvantage is that the acceptability of high-current charging is weak for materials used as high-power batteries. For the application of materials as energy batteries, the specific capacity needs to be further improved [8].

3.2. Lithium-Ion Polymer Batteries

Another type of battery is similar to lithium-ion batteries, which are polymer lithium-ion batteries. Its structure is generally the same as that of general lithium-ion batteries, which are also composed of positive electrode materials, negative electrode materials, electrolytes and diaphragms. The biggest difference between it and the general lithium-ion battery is that for the electrolyte, the polymer lithium-ion battery uses a solid or gel-like polymer electrolyte, which usually has soft, flexible physical properties. Lithium-ion batteries use liquid electrolytes, usually organic solvents containing lithium salts. There are also many differences in other aspects. For the shell and packaging, polymer lithium-ion batteries because of use polymer electrolytes and no metal shell to accept the electrolyte, so they use more please plastic or flexible material packaging.

In contrast, the outer packaging of lithium-ion batteries is a heavier metal shell. In terms of shape, polymer lithium-ion batteries allow for a greater variety of sizes and shapes, while general lithium-ion batteries are usually standard cylindrical or square. The ideal lithium-ion battery electrolyte needs to meet the following requirements: high ionic conductivity, oxidation resistance, thermal stability, high thermodynamic stability to lithium, non-toxic, environmentally acceptable, reasonable cost and easy to obtain when used in large quantities. The research direction of polymer electrolytes will mainly focus on the structure and ion transport mechanism research and the development of new solid polymer electrolyte materials so that polymer electrolytes can be used in human life and improve the living environment. With the emergence of new materials, new battery structures, and new production processes, polymer lithium-ion batteries will reach a new level [9].

3.3. Lead-Acid Battery

Lead-acid battery, a relatively old battery technology, uses lead and lead oxide as the main active substance and uses dilute sulfuric acid as the electrolyte. The composition is also similar to the above two kinds of batteries: positive electrode material (commonly used lead dioxide), negative electrode material (lead Pb), and electrolyte (dilute sulfuric acid). During the discharge process, the positive lead dioxide and the negative lead react chemically with sulfuric acid in the electrolyte to produce an electric current. When charging, the current flows in reverse, restoring the chemicals in the battery and making it fully charged again. Lead-acid batteries and old batteries advantages are also obvious: low cost (lead is rich, and sulfuric acid is also one of the common chemicals), mature technology (has been in development for many years, the production process has been optimized, efficiency has been improved to reduce the production cost), easy to recycle (recycling efficiency is high, the environmental impact is relatively small). However, compared with the rapid development of lithium-ion batteries in recent years, the shortcomings of lead-acid batteries are not difficult to find: low energy density (lead-acid batteries have low energy density, which means that they store less energy in the same volume), short cycle life (lead-acid batteries have relatively few charge and discharge cycles), low charge and discharge efficiency (large energy loss during charging). Although lead-acid batteries as an older generation of batteries, are not widely used now, they also have certain development prospects in EVs: Lead-acid batteries as a pure EV power supply in terms of specific energy, deep discharge cycle life, fast charging, etc., are worse than MH/Ni batteries, lithium-ion batteries, and are not suitable for small private cars; However, due to its low price, its application at home and abroad is positioned on buses - the speed is not high, the route is fixed, and the charging station is easy to plan. Due to the particularity of its operation, its required range can be greatly shortened [10]. Nevertheless, lead-acid batteries still have a place in some specific application scenarios, especially in cost-sensitive and low-battery performance requirements. (e.g., applications such as low-speed EVs, golf carts and electric bicycles)

4. Current Challenges with Electric Aircraft

4.1. The Energy Density of the Battery Power Supply

The energy density of a battery refers to the electrical energy stored per unit volume or unit weight of the battery, usually expressed in watt-hours per liter (Wh/L) or watt-hours per kilogram (Wh/kg). Energy density is an important measure of battery performance, which reflects how much energy a battery can store for a given volume or weight. For EVs, the energy density of the battery has a significant impact on the following aspects of the EVs: range, vehicle weight, space utilization, cost and efficiency. At present, the vast majority of electric instruments and vehicles not only require battery cells to have greater capacity but also constantly put higher requirements on their energy density. The original lithium-ion battery commercialized by SONY in 1991 had an energy density of only 80 W·h/kg; Today, the energy density of lithium-ion batteries has reached 300 W·h/kg [11]. At its "Battery Day" event, Tesla announced the 4680 battery, which features a larger cell size and a newly designed construction that is expected to significantly increase energy density. The collaboration with battery manufacturers such as Ningde Times aims to optimize battery design and production processes to increase energy density and reduce costs.

Another example is BYD's blade battery, which improves the energy density of the battery pack by designing the battery cell to be thinner and longer, similar to the blade. This design also improves battery safety and thermal management efficiency. Specific to the selection of materials in the development of high energy density batteries is the key to determining energy density improvement. For positive electrode materials, in order to further improve the energy density of lithium-ion batteries, it is necessary to consider three aspects: first, to develop positive electrode materials that can achieve high specific capacity at low potentials, such as high-nickel positive electrode materials; The second is to increase the lithium removal potential of positive electrode materials to achieve higher capacity,

such as high voltage LCO, NCM and lithium-rich manganese oxide cathode materials; The third is to develop positive electrode materials with high working voltage, such as lithium nickel-manganate spinel positive electrode (LNMO) [11]. In addition, there are many types of positive electrode materials. For the possible future electric aircraft, the energy efficiency of the battery also has the following important effects on its manufacturing: flight time and range (The flight time and range of an electric aircraft are directly dependent on the energy density of the battery. Batteries with high energy density can provide longer flight times and longer range, which is critical for commercial operations), aircraft design, and performance (the energy density of the battery affects the design of the aircraft, including the weight and volume of the battery pack. Reducing weight can improve the aircraft's load capacity and performance).

In contrast, reducing volume can optimize the aircraft's aerodynamic design), charging infrastructure, and operational efficiency (high energy density batteries can reduce the number of charges and charging times, improving the operational efficiency of electric aircraft And potentially reducing the requirements on charging infrastructure), cost, and sustainability (while batteries with high energy density may cost more, they could reduce the need for battery materials, thereby reducing long-term costs and improving the environmental sustainability of electric aircraft). In short, for electric aircraft, the energy density of the battery is a key factor that not only determines the performance and practicality of the aircraft but also affects its economic and environmental impact. With the advancement of battery technology, the manufacture and application of electric aircraft in the future will be more feasible.

4.2. The Impact of Battery Power on the Weight of Aircraft

The impact of battery power on the weight of an aircraft is significant in several key areas. First, it directly increases the aircraft's weight, as batteries are the primary energy source for electric aircraft. Typically, higher battery power results in greater weight, which influences the aircraft's take-off weight, load capacity, and overall flight performance. Second, battery power affects endurance and weight balance. While increased battery power extends the aircraft's range, it also adds weight, requiring designers to balance endurance and payload capacity. Heavier batteries can reduce the aircraft's commercial viability by limiting its load-carrying capacity. Third, battery weight influences flight performance, affecting acceleration, climb rate, maximum speed, and maneuverability. An increase in battery weight can reduce these metrics, impacting the aircraft's overall efficiency and handling.

Furthermore, heavier batteries necessitate stronger structural materials to support the additional weight, which further increases the aircraft's overall mass. Additionally, higher battery power demands more advanced battery management systems (BMS) to regulate charging and discharging, adding complexity and weight to the aircraft. Lastly, the increase in battery weight affects the aircraft's cost and operational efficiency, as heavier batteries may increase energy consumption (in hybrid aircraft) or charging requirements, raising operating costs.

5. Conclusion

In the past hundred years, fuel vehicles as one of the main means of transportation, but their inefficiency and environmental pollution problems have not been fundamentally solved. The emergence of EVs provides new solutions to these problems. EVs are not only able to reduce pollution and improve energy efficiency, but they are also advancing in technology. The core technologies of electric vehicles include battery technology, electric motors and electronic control. Among them, battery technology is the key to the development of EVs. At present, the types of batteries commonly used in EVs include lithium-ion batteries, lithium-ion polymer batteries and lead-acid batteries. These batteries have their characteristics in terms of energy density, cycle life, cost, etc., and are suitable for different application scenarios. As one of the development directions of future transportation, the design and operational efficiency of electric aircraft is significantly affected by the energy density of

batteries. Batteries with high energy density can provide longer flight times and greater flight range, which is essential for the commercial operation of electric aircraft. At the same time, battery weight also has an important impact on the overall performance of the aircraft. The increase in battery weight reduces the load capacity of the aircraft and affects its commercial viability. Therefore, aircraft designers need to find a balance between range and weight. As battery technology continues to advance, the manufacture and application of electric aircraft will become more feasible. The electric aircraft of the future will be able to provide more efficient operations while reducing their environmental impact. However, to achieve this goal, further breakthroughs in battery energy density, weight and cost are needed. In general, the development of EVs and electric aircraft is promising, but there are still some technical challenges. As battery technology continues to advance, people have reason to believe that EVs and electric aircraft will become an important pillar of future transportation.

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