Possibility of Building an Electric Plane: Starting from Existing Designed Models

Yijun Zhang*1

1Department of Physics, Grinnell College, Grinnell, Iowa, 50112, USA
*zhangyij@grinnell.edu

Abstract. Entering the 21st century, searches for alternative energy have become more and more significant to mitigate the gradual deterioration of the environment and the dearth of fossil fuels such as petroleum. As a result, plenty of scientists start resorting to electricity, one kind of clean energy produced by natural power like wind and water. Electricity has recently been applied to vehicles after decades of research, and the technology of the application doesn’t stop progressing. However, the application on vehicles is not just a destination but a starting point for electric aircraft. Nowadays, the research of electric aircraft has been started by several companies. This review begins with the rapid development of new energies, summarizes current existing models of electric aircraft from Airbus, Boeing, and other companies and agencies, considers the possibility of electric aircraft, and provides the prospect of building an electric aircraft in the future. The review concludes that while building electric airplanes is possible, and the size is restricted to be small enough due to the restriction of the energy density of the battery.

1. Introduction

1.1. The development of new energy
These years, plenty of countries start focusing on establishing regulation on currently used fuels because of their gradual decrease and the increasing reported cases of environmental pollution and climate change. In 2007, the world consumed 35.6% petroleum, 25.6% natural gas, 28.6% charcoal, 5.6% nuclear power, and 6.4% waterpower among the total energy consumption. It is overt that fossil fuel still took over 90% of the total energy [1]. Accompanying with the fossil-fuel-based structure, it often occurs of the acid rain from sulfur dioxide and the smog in the air. At the same time, it is also reported that the average temperature on the earth’s surface had raised 0.74±0.18℃ in 100 years by the time of 2005 [2]. Among the sources of pollution, aviation is one of the most significant origins. Airplane emits carbon dioxide causing the greenhouse effect and nitrogen oxides that increase the frequency of acid rain. The greenhouse gas emission of one international flight equates to that of one car in one year. The imminent dangers push people to find an alternative fuel to replace the old one, especially in the field of aircraft. In such a condition, new energy succeeded receiving unprecedented development, especially the conversion into electricity. Those conversions mainly include nuclear electricity, wind electricity, and hydroelectricity.

1.1.1. Nuclear electricity. Nuclear electricity originated in the 1950s. It mainly uses the chain reaction of Uranium-235 to produce a large amount of energy, enabling the water to transform into steam and push the generator. Once, it threatened the world with another usage-nuclear bomb, but the chain reaction has been able to control safely in this application. Nowadays, the electricity generated from the
nuclear plant has reached 394,282 Mwe, taking 10.5% of the global electricity generation, while the construction of nuclear plants of 58,501 Mwe has been set to goals. There were only 57 nuclear generators globally by 1970, but the number had increased to 2553 by the end of 2020 [3].

1.1.2. Wind electricity. The application of wind power has a long history. Humans started using wind power even before the first century. However, it is not until the 1970s, a period of the oil crisis, that wind electricity started to gain attention. As one kind of renewable energy that doesn’t pollute the environment, people could take advantage of the coast, mountain, and prairie areas where the wind is abundant to produce electricity. By 2019, the total installed capacity has exceeded 650,000MW and the growth rate per year was higher than 9.3% in 2016-2019 [4].

1.1.3. Hydroelectricity. The history of hydropower started in Greece in B.C.E 300 [5]. People used water mills to transfer the power of the flow to mechanical energy. The situation didn’t change until 1878 in England. Their project of hydroelectricity succeeded in lighting one lamp, which started the path for hydroelectricity.

1.2 The development of electric aircraft
The first electric plane model was built in 1957. It was a radio-controlled model aircraft equipped with a permanent magnet motor and silver-oxide battery. In 1973, Fred Militky and Heino Brditschka built Militky MB-E1 with one motor glider. In the test, Militky MB-E1 flew for around 14 minutes successfully. It could be considered the first real electric plane. Followed by the first prototype, several electric aircraft was successfully built and tested by individual scientists. However, because the technology was restricted, neither of these electric planes showed high speed or long persistence during flying. Mauro Solar Riser, whose capability is only one person, built in 1979, could only fly for 3-5 minutes following a 1.5-hour charge. Although the goal of applying electricity on aircraft had been achieved, the application could not spread.

Entering the 21st century, the improvement of technology accelerated the development of electric aircraft. One of the most significant progress is the battery. Instead of using traditional secondary batteries, a Lithium-ion battery is being applied. It obtains the highest energy density and specific energy,
which means that using a Li-ion battery could reduce the mass and volume of the battery set in the aircraft and offer more energy to the engine. At the same time, the advent of solar cells provides another possibility as well. By converting solar energy into electricity, solar cell aircraft could gain infinite power in the daytime, so the mass of the aircraft could be reduced as well.

1.3 Difficulty in the development of electric aircraft
Accompany with the prominent development, and scientists are confronted with harder problems when designing electric aircraft. The energy density, one factor that controls energy storage capacity, has been considered the biggest problem. Enabling a jumbo jet to take off, fly for hundreds of kilometers and then take off requires thousands of kilograms of battery [7]. However, the jumbo jet is even unable to take off with such a weight of batteries. If the weight of the battery was reduced, the distance of the flight would be restricted. To overcome the dilemma, it is required to improve the energy density of the battery. So far, Lithium-ion battery is considered to be the best performance battery, but this battery has reached its maximum performance and could hardly be improved based on years' research. What's more, even though the Lithium-ion battery can be applied on the aircraft, the energy stored in it is far less than that stored in jet fuel. The energy density of Lithium-ion battery had reached 350 Wh/kg in 2020, while the energy density in jet fuel is 12700 Wh/kg [8]. The battery doesn't need to exceed the performance of jet fuel, but several minimum values are set for them. If one electric flight wants to obtain a range of 1,111km (600nmi), the energy density must be higher than 800 Wh/kg; if the range doubles, the energy density should also double [9]. Fig.2 shows that 600nmi and 1200nmi cover almost all domestic airlines, but these airlines are not achievable only with Lithium-ion batteries.

Another difficulty comes from the cost. Although the lithium battery price decreased to 156 $/kWh from 1,183 $/kWh in the past 10 years, meaning that the battery pack may not be a main source of the cost, people may not afford the cost for charging the battery. The large amount of electricity used for charging cannot be generated only from wind or hydro power but also from fossil fuel. Using electricity from fossil fuels is not what people expect to reduce the influence of pollution and climate change. On the contrary, it may even worsen the problems. Fig.3 shows the reference jet engine aircraft, Airbus A320neo. The electric aircraft is equipped with batteries with an energy density of 800 Wh/kg (grey lines) and 1,200Wh/kg (blue lines). Each king of battery costs either US$100/kWh or US$200/kWh. For the battery with 800Wh/kg, jet fuel price has to be at least 2.3 or 2.8 dollars per gallon for the case of the cost-effectiveness relative to jet engine aircraft in light of the 2015 US electricity end-use prices [10].
2. Current condition of electric aircraft

Currently, there are two main companies, Airbus in Europe and Boeing in the United States of America, leading the research in the field of electric aircraft. However, other agencies and academies are also contributing to the development. Neither of them has applied the same method to overcome the difficulties.

2.1 Development of Airbus electric plane

Airbus starts its research in 2010 with the prototype called CriCri. It was regarded as the first 100% electric aircraft in the world. In the following years, Airbus continued revising and building new test models in small size. In 2017, Airbus started its first attempt, E-Fan X, in middle or large sizes [11]. E-Fan X was equipped with a 3,000V DC supply as the electric power source. With one of the four engines replaced with an electric engine, E-Fan X could test the electric engine while avoiding the fear of problems from the battery set. E-FAN E-Fan X was the first attempt on the progress of full-electric middle-sized aircraft for Airbus and the last one since the battery could not provide enough energy to support such a huge plane. On the other side, however, E-Fan X successfully offered Airbus another idea of hybrid power.
In recent years, Airbus has released its newest design, ZEROe. There are three types of aircraft in ZEROe, Turboprop, Blend-Wing Body, and Turbofan. The first one was designed as small, which would serve for short flights while the other two services for the middle and long flights. Each of them could fly at least 1,000 nautical miles (1852km), which means the power supply cannot be battery only. In fact, Airbus designed them as hybrid power consisting of hydrogen internal combustion and hydrogen fuel cell. The specific energy of hydrogen is 40,000 Wh/kg, which is even much higher than jet fuel. What's more, the product of the combustion is only water.

Although using hydrogen hybrid power can reduce pollution, it also consists of several problems. Firstly, Airbus hasn't figured out where to store the fuel on the plane. Spaces are highly restricted on aircraft, so there won't be large room for fuel storage. Given the fact that hydrogen is gas and the weight is small, it would be difficult to ensure enough fuel for flight on such a plane. Secondly, hydrogen has a high potential to explode. The explosion limit for hydrogen is between 4.0% and 75.6%. The disaster of the Hindenburg in 1936 was widely known that the leak of hydrogen gas caused the explosion. Aircraft, whose flying speed and altitude are much higher than the airship, suffer from more threats. If people
want to ensure enough fuel, they need to compress the hydrogen gas to minimize the room, but low pressure and temperature give more tasks for hydrogen gas storage.

2.2 Development of Boeing electric aircraft

Different from Airbus that persists in independent research, Boeing preferred supporting small companies' research. In 2019, it bought a company called ZUNUM Aero. This company is currently designing a middle-sized plane that could take at most 27 passengers [14].

According to the design, the plane can fly 700+ miles (1,126+ km) with a speed of 340 mph (547 km/h) with the help of a 500 kW engine. With a smaller size plane, the mass of the battery could be reduced as well. The battery only weighs 20% of the maximum take-off weight (11,500 lbs). However, ZUNUM Aero still designed it as a hybrid aircraft (jet fuel and electricity) due to the difficulty of overcoming the threshold of the battery's energy density. To overcome the shortage of short flight distance, ZUNUM Aero has come up with a new idea.
While we are familiar with international airports such as Los Angeles International Airport and John F. Kennedy International Airport, we ignore many small city airports. Due to their weak aircraft throughput, those airports failed to become destinations of international or even domestic flights. However, small hybrid aircraft can take off and land at such small airports. Another advantage is that even though the speed is lower than the normal traditional flight, the flight will take a shorter time while passengers are boarding and getting off the plane. In total, the time for the journey is even shorter than the traditional flight [14]. By taking advantage of small airports, ZUNUM Aero could build a transfer net of flights across the state and even the whole country like "Electric taxi" [15].

2.3 Development of other companies and agencies about electric aircraft

While the world is paying great attention to Airbus and Boeing, several companies are making efforts in designing electric aircraft, not only from the overall design but also from the design of components. Rhyxeon General Aircraft Co., Ltd. (RGAC) in Shenyang, established in October 2013, is a subordinate enterprise of Liaoning General Aviation Academy (LGAA). These years, it is aiming at mini-size electric aircraft that could hold 2-4 passengers. The progress was little at the beginning due to the bad performance of the battery, but recently they have made a prominent improvement. The new battery set could hold an energy of 70 kWh, and the energy density exceeds 300 Wh/kg, which has become the most powerful battery used for electric aircraft in the world. In 2018, the model RX1E-A (600kg) could hold 2 passengers and only fly for 2 hours with the old battery. After being equipped with the new battery, the plane could fly for 2.5 hours. Even though RGAC has already started producing electric aircraft with the help of their new battery, neither of them could fly over 2.5 h or 300 km [16].

While some academies are designing aircraft, others are paying attention to the battery. State Key Laboratory of Clean Energy Utilization of Zhejiang University in Hangzhou proposed new material for hydrogen storage. AlH$_3$, one kind of solid whose density is only 1.48 g/cm$^3$, obtains the ability to store one time higher than pure liquid hydrogen in the same volume, two times higher than the method of high-pressure storage. At the same time, it could also release the hydrogen gas at a constant rate [17]. Consequently, the danger of hydrogen explosion can be reduced. However, the application of AlH$_3$ becomes another problem. Due to the restricted chemical reaction, AlH$_3$ is not affordable for commercial flights. Therefore, the application of AlH$_3$ could be achieved only after the production method is improved.

3. Conclusion

The attempt to build electric flight manifests the hope of human beings to reduce environmental pollution, ameliorate the greenhouse effect, and extend the research of technology. It offers another path for applying electricity and battery, which has been currently researched on vehicles. Unlike the condition of electric vehicles, the condition of electric aircraft is more complicated, including frequent fluctuations, low temperature, and low pressure. Although electric aircraft research is confronted with more difficulties, it enables scientists to liberate their minds from electric vehicles. For example, a lithium battery is powerful enough for electric vehicles but cannot support electric flight aircraft. At the same time, lithium battery also reaches its maximum power density. All those factors may encourage a new form of battery in the future for electric aircraft.

Based on the current model and research, we are now able to build electric aircraft. Still, the size of the aircraft is limited into mini sizes that could travel for several hundred kilometers because the battery's performance cannot meet the flight for a long journey with a large number of people. Pursuing 100% electric middle or large-sized aircraft still requires us to wait for decades. However, hybrid power aircraft, which replace part of the jet fuel with electricity or replace all the jet fuel with clean energy such as hydrogen, is more achievable than the former, based on examples in the article. The success of electric aircraft not only requires the endeavors of individuals but also needs cooperation between companies, academies, and agencies. By sharing different opinions and research accomplishments in cooperation, it will be less difficult to achieve the goal of electric aircraft.
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