Existing problems and the future of electric aircraft

Xiao Peng[1, *, †], Haoming Xu[2, †]

[1]School of Energy, Power and Mechanical Engineering, North China Electric Power University, Beijing, Beijing, 100096, China

[2]School of Science, Applied Chemistry, Northeastern University, Shenyang, Liaoning, 110819, China

*Corresponding author's e-mail: 120191330103@ncepu.edu.cn

†These authors contributed equally.

Abstract. At present, the air traffic becomes more and more important to people's daily life and the aviation industry has exposed to many problems to be solved. Now, the air bus have become one of the most significant way of transportation and its high fossil fuel costs and low efficient overwhelmed people. Electric planes are seen as one of the solutions because many advantages they have although there still exist lots of difficulties. This article explores the advantages of electric aircraft: the reason why it is fabricated and the problems along with the process and what the future is be like. This paper represents many factors of the all-electric plane's edges like the efficiency and the environmental friendliness. The study sums up a comprehensible conclusion about this transport. As for the difficulties, the essay also describes the electric propulsion system of an all-electric jet and analyses the reasons why it has not yet been successfully commercialized including the specific energy of the battery, capacity, temperature and other problems. People will focus on them in the future and this report will provide some information. This article shows that while there are still too many difficulties for scientists to make a practical one, people have made some breakthrough through past few years, and people will soon fabricate the real one.

Keywords: air traffic, electric aircraft, All-electric jet engine, electrical propulsion system.

1. Introduction

With the vigorous development of the society, people have a greater keen on all-electric vehicles because traditional transportation may cost more fossil fuel and be very harmful to our circumference. Now, the all-electric jumbo jet comes to people's sight because it has more advantages than the traditional aircraft like it is more environmentally friendly, more efficient and has lower cost. The global airbus market displays successively increasing trend on selling aircraft which means there exists huge potential to develop the all-electric jumbo jet. Many people have done a lot of work on the research of the all-electric aircraft and the article do summarize the advantages of the all-electric aircraft which is the reason why people devoted all heart into this process. This study makes a conclusion and use some examples to illustrate our opinions and discoveries.

But there are still lots of difficulties to totally create an all-electric airplane especially the battery which is the most significant part in the aircraft. This article will represent three factors that have great influence on batteries. The first one is the weight of the cell. When storing the same amount of energy, the jet fuel can be much lighter than the battery which means the traditional fuel can be more efficient and practicable. Also, the heavier the batteries are, the less range the aircraft can achieve and the jet may not have enough power to fly. The second problem is the temperature. The heat dissipation evaluation is a crucial parameter to appraise the battery working situation. People can expand batteries' cycle life and ensures the all-electric plane security by reducing the heat which is consumed in the process of the operation. The third one is the battery capacity. The battery can use on an all-electric car now because it can be made in a small size with high energy density to keep the car driving for a long range. But for the aircraft, people still cannot make a suitable cell that have enough power to drive the battery powered jet.

So, the paper demonstrates a comprehensive conclusion towards the all-electric aircraft, containing the edges, technique difficulties and the development in this article. Although people have not yet figured out all the problems, scientists do have make a big progress on each of the difficulties. This report intends to introduce the details of the current evaluation of the electric plane and three main difficulties which scientists still fight for and display the recent development to the all-electric plane.

2. The importance of all-electric aircraft

Today, air traffic is becoming more common, and people tend to use air traffic for rapid passage during some journeys. However, this trend increases the burden of air traffic and increases its energy consumption and impact on the environment. How to solve these problems can even influence the lifespan of aviation. Known from long-term market forecasts that the growth rate of air traffic reached 4.4%. This growth will bring more air pollution, and the line chart reconstructed annual carbon dioxide emissions of the global aviation dating back to 1940 (Figure 1).

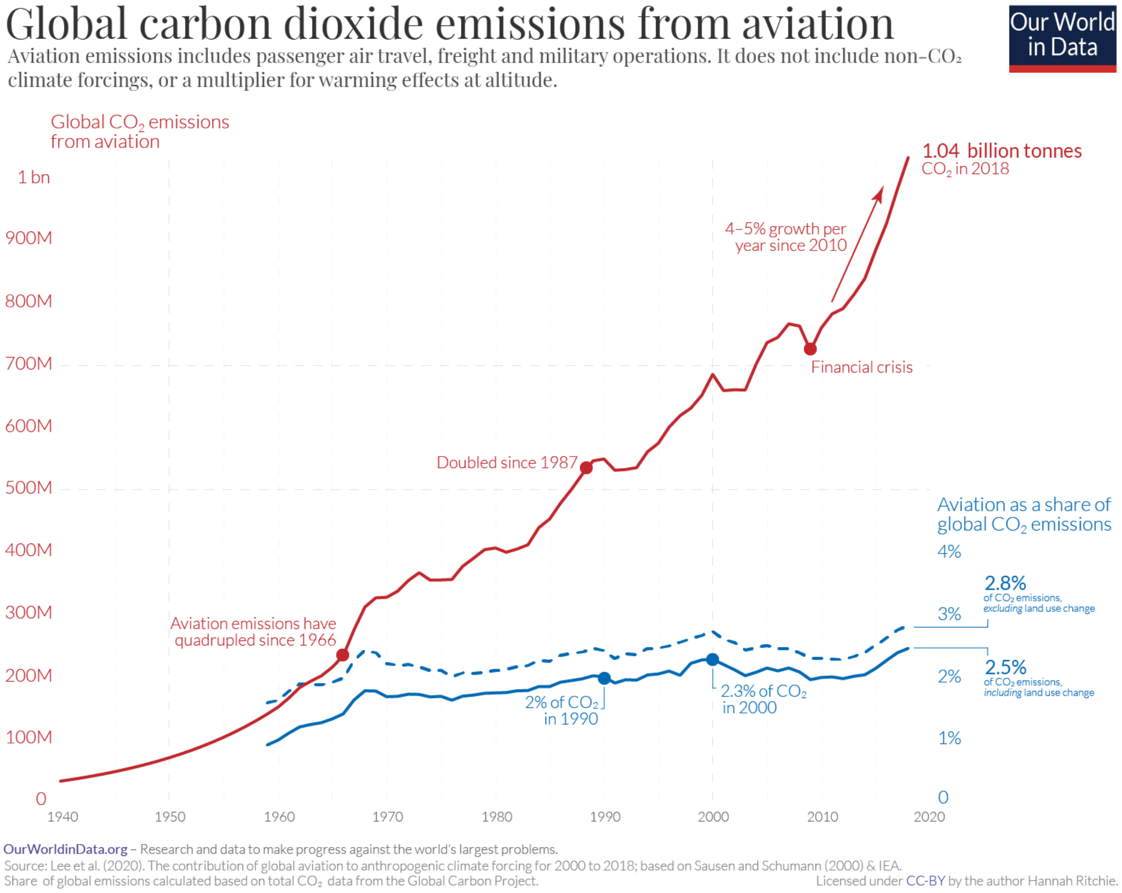

Figure 1. Global carbon dioxide emissions from aviation (Our World in Data, 2018) [1].

According to this article, 1.04 billion tons of carbon dioxide were released into the atmosphere in 2018 as the consequence of worldwide aviation, which includes both passenger and freight traffic. 2.5% of all carbon dioxide emissions in 2018 came from this source. Even scarier is that emissions from the aviation industry have doubled in the last 30 years. And there was a sharp increase from 2010 to 2018. That means there could be more carbon emissions in the future.

In order to deal with possible climate problems and enable the sustainable development of the aviation field, NASA set out the directions as early as 2008. 1)To reduce the noise of the airport. 2)Trim emissions (both pollutants and greenhouse gasses). 3)To cut off the burning of fossil fuel. And set performance goals for these corners in “NASA SUBSONIC AIRLINER PERFORMANCE GOALS” plan. In this plan, there are high requirements for future aircraft. In terms of noise, it is required to reduce 55 dB (relative to stage 4) and to reduce nitrogen oxide emissions by 75% [2].

These numerical requirements may be a bit radical, but they show the destination where the industry is heading. And the development of electric aircraft is in line with this expectation.

3. Advantages of the electric aircraft

Electric aircraft offer several benefits over those driven by traditional gasoline. It has low noise, zero emission, high safety performance, power does not change with altitude and temperature, low operating cost, constant weight and centre of gravity during flight, has low energy loss, and so on. Here are a few detailed comparisons.

3.1. Low noise

In terms of noise comparison, two types of comparisons are made,1) Noise evaluation of different propulsion systems for propeller aircraft. 2)Noise comparison of large commercial air vehicles.

Two propeller planes, Extra 330 and Magnus Fusion, were selected for comparison. Each airplane has a propulsion system that either uses an internal combustion engine or an electrical motor. After measurement, it is found that after replacing the internal combustion engine with an electric motor, the noise at all frequencies is reduced under various speeds and heights. Noise reduction up to 22%. (Including the noise monitored outside the aircraft and the noise inside the aircraft cabin.)

After sound source localization, it was found that when the aircraft uses the traditional internal combustion engine, the main source of its noise is the intake and exhaust parts of the engine. When the electric propulsion system is used, most of the noise is generated by the interaction of the external components of the aircraft and the interaction between the propeller and the air. This shows that the use of electric propulsion has a significant noise reduction effect for propeller aircraft [3].

Because large electric jets do not exist today, the empirical relationships have been used to make predictions about motor noise. The overall sound power levels are expected to be about 8 to 20 dB lower than noise made by fans for a 1 MW motor powering a regional jet-size aircraft and around 17 to 29 dB lower for a 13.8 MW motor operating an aircraft of 737-size [4].

3.2. Low emission of pollutants

Airplanes powered purely by electricity should have zero emissions. But today's electricity supply still comes partly from the burning of fossil fuels, which also produces emissions. By weighting the different sources of electricity and calculating the specific fuel consumption (based on BSFC 300 g/kWh) of the aircraft fuel, people obtained the data shows in the Table 1. Electric aircraft have clear advantages in pollutant emissions, and this advantage will become more obvious with the greener way of supplying electricity in the future.

Table 1. Comparison of emissions of various pollutants from different energy storage mode [5].

In Gram Per 1 kWh Shaft Power	AVGAS 100LL	AVGAS 100LL with LCA	All-Electric	All-Electric with LCA
CO2	600	600 × 1.8 = 1080	179	344
CH4/HC	4.5	4.5 × 1.8 = 8.1	5.4	10
NO	1.5	1.5 × 1.8 = 2.7	0.8	1.536
SO			10	19
PM			1.25	2.4
Water Vapor	360	360		
CO	300	300		
lead	0.24	0.24		

3.3. Higher economic efficiency

Higher economic efficiency is the fundamental reason driving the development of electric aviation. For routes under 500 miles, the advantages of small electric airliners are clear. Take small passenger aircraft turbo-prop Cessna Caravan as an example, a 100-mile journey will cost $400 with regular fuel, but only $8-$12 if using electricity [6].

But under market conditions prior to 2019, it's possible that first-generation all-electric narrow-body aircraft can't compete with jet aircraft in the economical aspect. Because after calculation it is known that at that moment, electric planes were only more economically advantageous when jet fuel prices exceeded $100 per barrel [7]. Since the outbreak of the covid-19, the price of jet fuel has soared up to ＄146 per barrel. And the development of batteries and other aspects has also further reduced the cost of electric aircraft. So now large electric passenger aircraft has also begun to have higher economic benefits, providing new possibilities for the development of the aviation field.

3.4. Higher energy transfer efficiency

Then compared with traditional aircraft, it has higher energy transfer efficiency, as shown in figure. 2.Energy will be lost in the process of transmission, and the energy conversion efficiency of differe nt propulsion systems is also very different.

The result is obtained by estimating and calculating the energy loss on the whole energy chain. Fuel is only 52.1% inefficient in thermal energy conversion, and the energy utilization rate of the entire conventional aircraft propulsion system is only 43.1% after calculations. For the all-electric propulsion system, although it has more energy conversion steps, the final results is 49.6% because of the high conversion efficiency of each step.

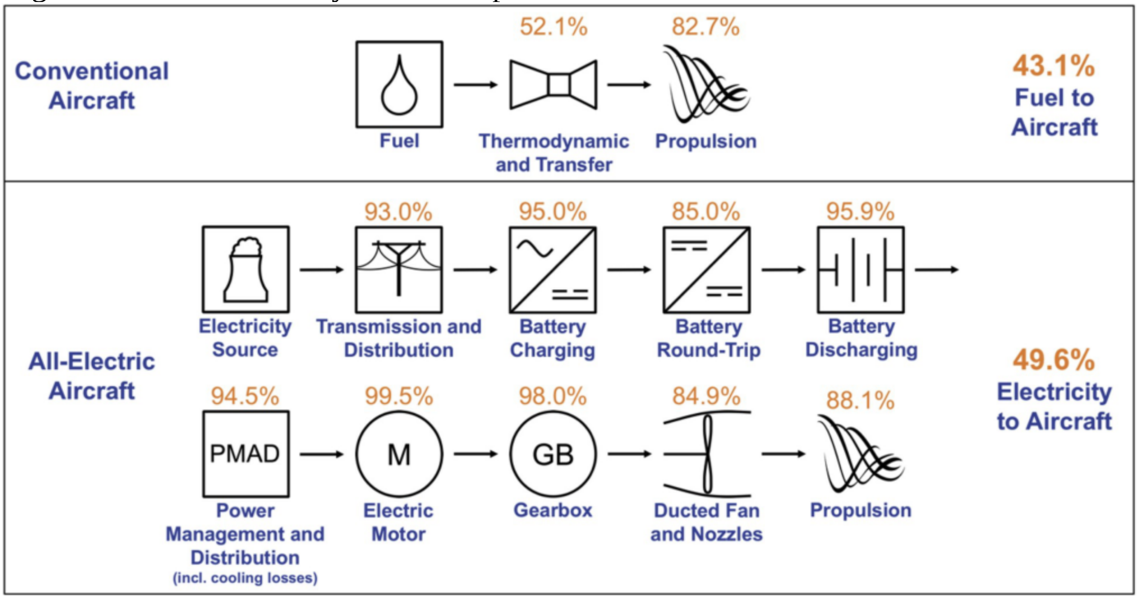

Figure 2. Conventional and AEA energy conversion chain comparison [8].

4. All-electric jumbo jet

Despite there are many advantages of electric aircraft, it is only a small part of the market. Jets make up 75% of the entire aircraft market, and it's not successfully electrified. Because the development of this technology also faces several core difficulties. For example, all-Electric jet engines still have big vulnerabilities, the maximum range is limited, the payload is not high, the motor power density is low, and the battery performance is significantly affected by temperature, etc.

4.1. Electric propulsion system

The all-electric jets use electrical propulsion as the power has become a reality. But only it meets the requirements of the commercial flying, they can be a really alternatives. Electric propulsion types can be categorized into six distinct kinds of types, they are displaced in figure 3.

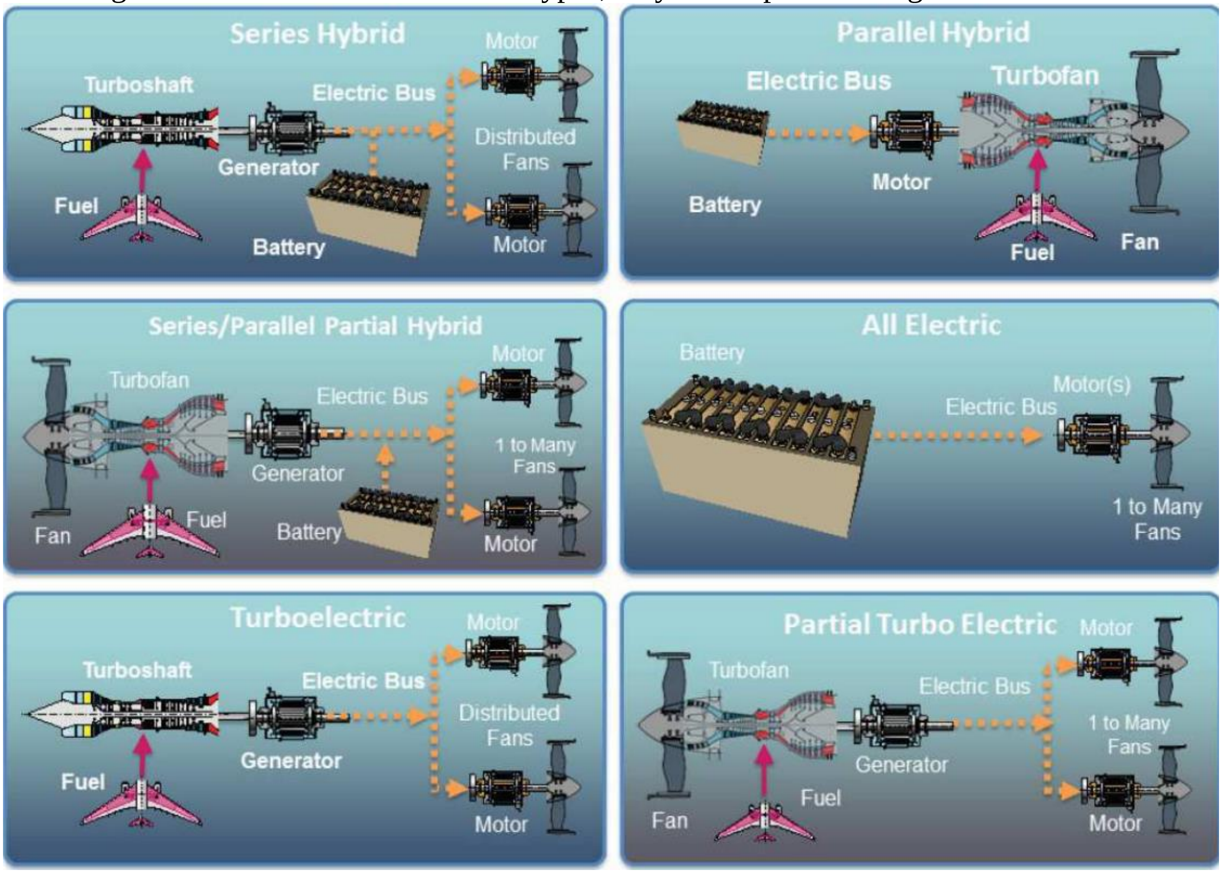

Figure 3. Types of electric propulsion (NAP 2016) [9].

Batteries are the only source of the all-electric systems for power propulsion. The hybrid electric systems combine batteries and gas engines as the main power to drive the aircraft. The gas turbine can serve the batteries as the extra source and it is also the main power of the propulsion. These batteries can create more energy for the flight. The turbine and batteries are constructed in the same shaft in the parallel hybrid system, which means both are capable to produce the power for the propulsion process. The electric motors serve as the unique energy that have ability to connect to the fans for the series hybrid system; the gas turbine serves to ensure the operation of electrical generators and the output generator can charge batteries or drive motors. The parallel partial hybrid or series system incorporate with some extent of fans that can be controlled by other fans which depend on electrical motors especially or by the gas turbine. Considering the process of the turboelectric propulsion, which does not require batteries as the propulsion energy in the flight. The full turboelectric drives the process of electric generators propulsion by using the part named turboshaft, which is the energy of the inverters and eventually single direct current motors where individual distributed electric fans are driven. The partial turboelectric supplants the turboshaft for a gas turbine. So, some propulsion processes depend on all-electric power and the rest of the energy is produced through the gas turbine [9].

All-electric turbojets face even bigger problems, this may require the arc to generate a plasma to heat the gas (Figure 4). This is difficult to achieve in the atmosphere because it requires very high temperatures, and the propulsion is not very efficient.

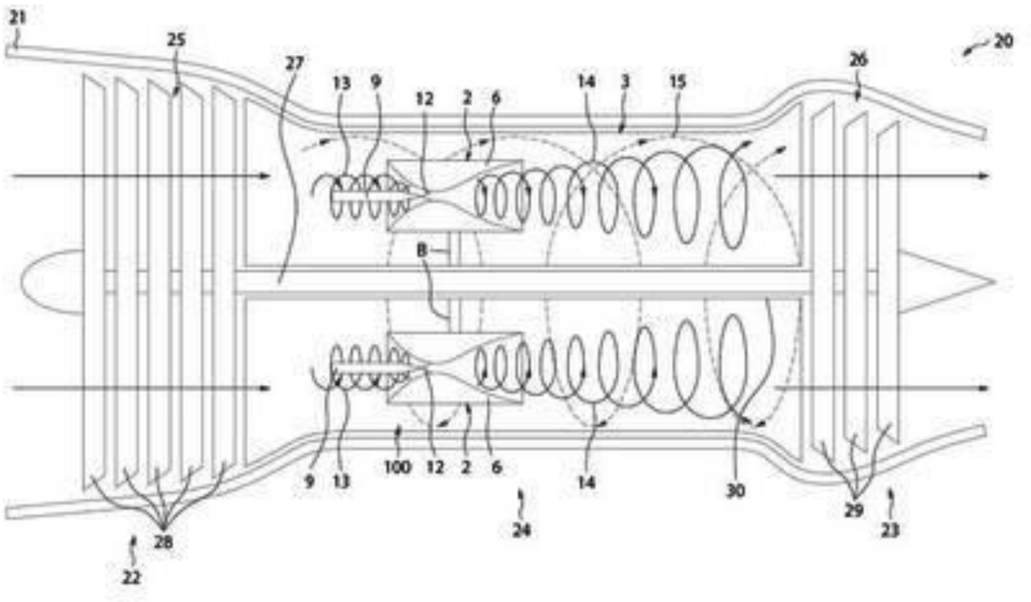

Figure 4. Envisioned electric turbojet engine [10].

Comparing the traditional combustion propulsion with the all-electric propulsion, the factor of weight is a significant parameter to consider. As batteries have ability to serve as the energy capacitor, the efficiency is appalling compared to fuel. For instance, 1 kilogram Jet fuel can store about 60 times more energy than most of exist batteries which using the technology of Lithium-Ion. And comparing the space efficiency, the jet fuel for one liter can have 20 times more power than the Lithium-Ion battery when they have the same volume. But in the air industry, the difficulty does not have a big deal with the space, but the weight has a significant function. In the weight aspect, jet fuel with one kilogram can store approximate 11.900 Wh of power, and at the same time Lithium-Ion battery with one kilogram can only store 200 Wh of power. The following process is about considering more about the efficiency when transforming the storage energy into movement. The most modern electrical motor can have 95% efficiency which is at very high level. The core of the modern gas turbine has only near 55% efficiency of changing the fuel power used in Jet into work of shaft. So, the weight of batteries is really a big problem that has a significant influence on the properties of the all-electric plane.

Scientists still have a long way to go to find a suitable solution to apply the all-battery propulsion into the aircrafts [9].

4.2. Maximum range problem and solutions

So far, most of the batteries do not meet the needs of electric jet aircraft, and only a few batteries are theoretically feasible. These theoretically feasible batteries include lithium sulfur battery, graphene battery, lithium-ion battery and fuel cell, etc. Figure 5 shows the comparative distribution of energy density and specific energy of various existing batteries and fuels. The figure shows that even the lithium battery with the best performance so far (Does not contain Amprius' silicon nanowire lithium-ion batteries and Li-S batteries) has a huge gap with the aviation fuel currently used (The energy density of this battery is 5.6% of that of aviation kerosene ,and its specific energy is only 1.7% of aviation kerosene) [11].

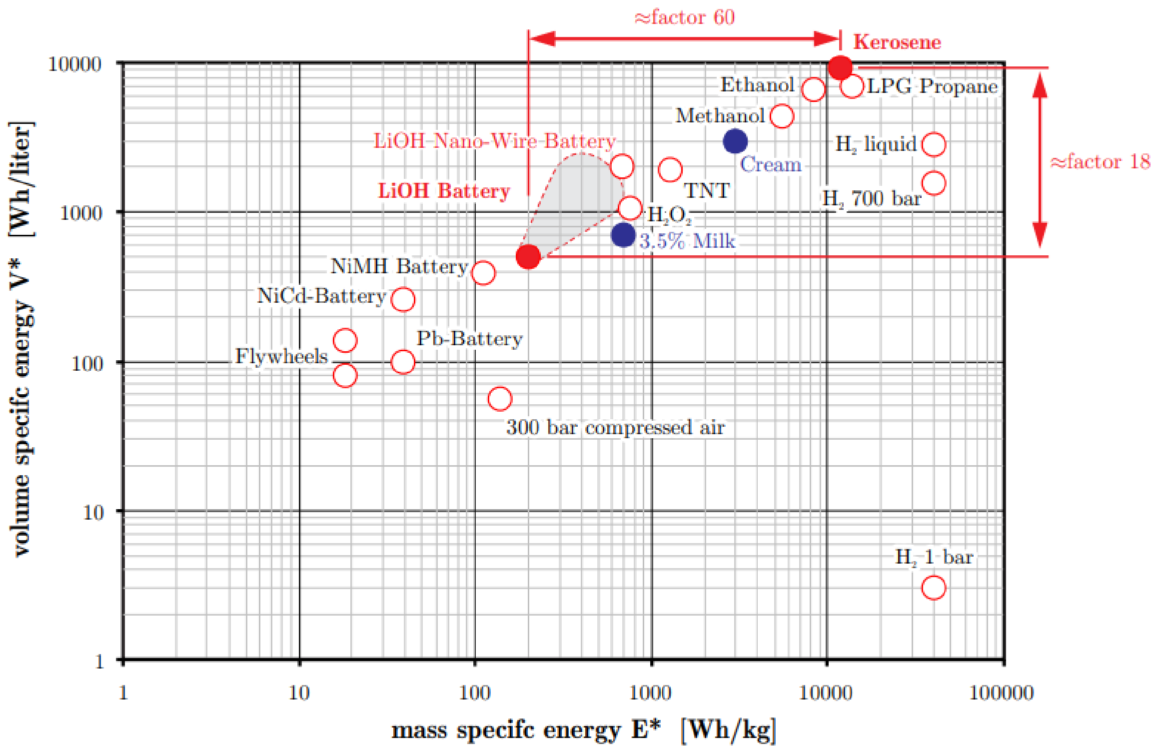

Figure 5. The comparative distribution of energy density and specific energy of various existing batteries and fuels [11].

For a commercial electric aircraft, it cannot be recharged in the air, and its weight remains essentially the same after takeoff. This makes its range very dependent on the amount of “energy” it carries at takeoff. Therefore, when the specific energy of the battery is very low, more batteries are required to carry more energy. However, the increase of batteries also increases the net weight of the aircraft and accelerates the energy consumption. This contradiction restricts the development of large commercial electric jet aircraft. Boeing has proposed a concept called "SUGAR-Volt" and taking NASA's project “subsonic airliner performance objectives N+3” as the target, figure 6 is finally obtained.

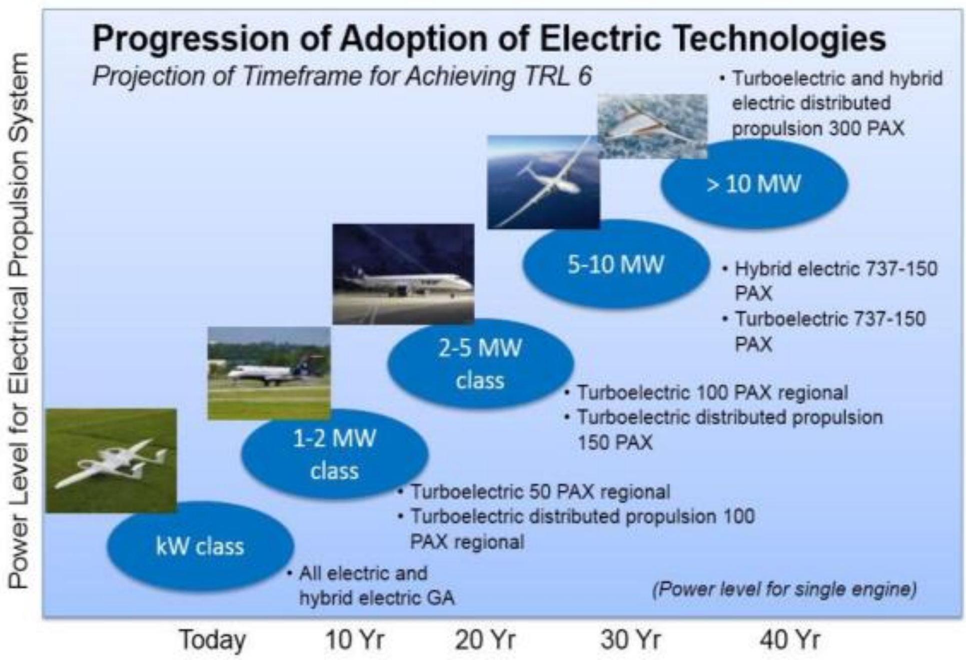

Figure 6. Future development plan of commercial electric jet aircraft [12].

From this prediction, people can know that the future large commercial electric aircraft will have high requirements for power level. However, based on the above reasons, existing batteries cannot meet this requirement, which highlights that the problem of battery specific energy needs to be solved urgently.

To expand the range of electric aircraft can be done in two ways: 1) Use electric hybrid; 2) Increase the energy density and specific energy of the battery. A hybrid of hydrogen and electricity can be used (Figure 7). Using a high-temperature superconducting rotating electrical machine as the core. Using liquid hydrogen as coolant and fuel (Liquid hydrogen needs to be preheated before it can be used as fuel). The electricity from the generator and the electricity in the battery are transmitted to multiple electric motors for driving [2]. This not only increases the range of the aircraft, but also increases the power density.

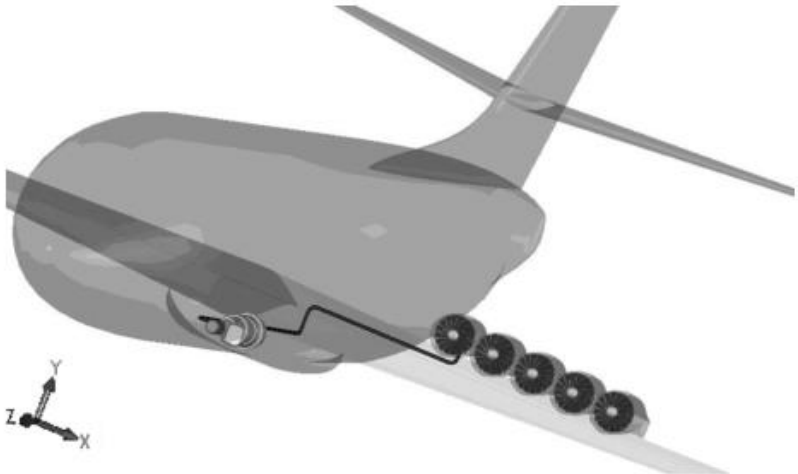

Figure 7. Super-conducting electric propulsion [2].

The lithium sulfur battery's theoretical specific energy is very high, reaching 2567 Wh/kg. This is sufficient for most commercial airliners. However, the development of this technology is limited by many problems: 1) since sulfur itself is a non-conductive material, its conductivity is very poor, which is not conducive to the high rates performance of the battery; 2) Lithium polysulfide is soluble in electrolyte; 3) sulfur is similarly to silicon, and there will be obvious volume changes during charging and discharging, which will easily lead to battery damage. This will increase the use cost [13,14].

4.3. Temperature problems and solutions

In order to make the best use of the batteries in the all-electric jumbo jets, the cooling system must be more effective and balanced so that it can ensure the transportation can work safely and completely. People will be very unpleasure to get temperature distinctions between batteries and battery modules. So far, there have been much research on batteries cooling process to figure out more methods that can improve the property of the batteries. These include heat pump cooling, phase change material cooling, air cooling and liquid cooling [16]. In order to find out the best method of cooling among them, people discovered a novel cooling way through changing the sets where air will be outlet and inlet often. The result shown that the air outlet and inlet in distinct places and the use of separators to divide airflow is the best result. Li et al. [17] carried on the analysis of batteries in thermal aspects numerically and experimentally. Besides, the team employed water for the process of cooling. In huge amounts of studies, the thermochemical model was always made comparison with experiments. Voltage, temperature and current analyses were displayed through experimental and huge amounts of research. They claimed that employing water for the process of cooling at low cycle rates performed as a very useful way to solve the problem. It was said that mixed systems could be applied for the process of cooling when the cycle rates are larger, where only the way of water cooling seemed not enough. Wang et al. [18] carried out the batteries analysis in thermal part with the method of phase change material (PCM). The team tested the outcomes empirically and repeatedly. They found out that thermal conditions are changed by the power stored by the PCM, batteries' configuration and cycles change of charge and discharge. As a result, they found that the mix of reciprocating cooling flow and hysteresis control displayed that it had the best performance of cooling according to the heat pipes which they employed to evaluate the cooling degree.

So, the thermal problem towards the batteries of the all-electric jumbo jet can have the solution in the future. But the technology is still immature like people cannot employ the water-cooling system into the real electric aircraft. There is still a long way to go to work out the thermal problem on batteries thoroughly.

5. Conclusion

All in all, although there still exist lots of difficulties waiting to solve, the future belongs to the all-electric jumbo jet on account of its promising performance in many different conditions like low cost, more efficient and environmentally friendly. It can be seen in this paper that comparing to the problems, the benefits human can get from the all-electric aircraft are much more valuable, which means it is worth to develop. Although the three problems mentioned in the report remain very challenging to scientists, but they are looking forward to the future. It is obvious that the weight of batteries restraints the development of the airplane like the suitable batteries for the all-electric aircraft can only power a low distance. The thermal problems also have a long way to go although people found the water-cooled system can decrease the bad impact effectively, but there still exist a distance to apply it on the real situation. The capacity of battery has no advantages when it compares to the traditional fuel, which have lower volume and much more energy storage to keep the aircraft goes far and energetic. More and more industries come to develop more electric aircraft as they seeing it as the future of transportation. The future belongs to the all-electric jumbo jet and people expect to see it.

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