

Advancing Power Supply Devices for Electric Aircraft

Yinuo Wang^{1,*†}, Luoming Zhang^{2,†}, Qiaoyi Zhou^{3,†}

¹ Christ's Hospital School, Horsham, West Sussex, RH13 0LJ, United Kingdom

² Suzhou Foreign Language School, Suzhou, Jiangsu, 215004, China

³ Nanjing Foreign Language School, Nanjing, Jiangsu, 210000, China

* Corresponding author: 16wangyx@christs-hospital.org.uk

†These authors contributed equally.

Abstract. The pollution caused by the construction of more aircraft that run on fuel will become more severe as more fuel-energy aircraft are built. As a result of the numerous environmental crises currently confronting the world, electric jumbo jets need to replace those that run on fuel. Note that the most interesting issue would be the airplane's power supplies. Research is conducted on the physical principles underpinning solar panels and power beaming. Batteries are an essential component of electric aircraft. The materials used to construct airplane batteries are among the most crucial aspects of battery design, and lithium-ion batteries are among the top options available. The capacity of the batteries will not decrease over time, and they will not catch fire or put passengers at risk. In order to maintain charging, a one-of-a-kind combination of sulfur and selenium is utilized. It has been discovered that solid sulfur selenium batteries have a good touch, do not ignite, are thinner (even thinner than lithium-ion batteries), and have a higher capacity for storing energy than lithium-ion batteries.

Keywords: Power supply, electric aircraft, solar photovoltaic, photovoltaic system, energy.

1. Introduction

As professor Colm explains, the necessity of electric aircraft, for instance, the improvement of mobility in the cities, the reduction of environmental footprint, the sustainable growth of the aviation industry, and electrified aircraft, can redefine the meaning of flight. The problem being researched is the reduction of environmental footprint and the improvement of mobility. Electric planes have the potential for a variety of applications, including observation and monitoring, because of their quietness and maintainability. However, because an electric aircraft relies only on the power stored in its batteries, it has a much shorter flight time than a gasoline-powered aircraft, limiting its usage range. On the other hand, electric aircraft might increase their flight periods and utilization range by feeding power from an external power source. The electrified aircraft's power supplies are one subtopic that interest people. The reason for tackling these problems is that the batteries that store the electricity for the whole airplane are insufficient for the whole flight, so this introduces a question about what extra material or equipment can be applied to the aircraft to maintain the lift generated by the airplane.

According to companies like NREL and SHARP, many of the researched technologies are still undergoing testing on a smaller scale, and they are not yet ready to be used in a commercial setting. This was the situation at the beginning of the research process. Additionally, the shift in altitude and temperature will assist in completely using the output, as detailed in the following paragraph that makes up the main body of the text. Furthermore, there are more possibilities for transferring electricity, such as power beaming, which involves shooting a laser into a receiver beneath the plane. The receivers then convert a single wavelength of light into electric power while maintaining high efficiency. According to the study's findings, the output efficiency can reach approximately three-quarters of the input, which is more than double that of a conventional solar cell.

2. Power Supplies

2.1. Solar photovoltaic (PV)

The input rate at the Earth's surface receives about 1400 Wm^{-2} of energy from the sun. The solar panel receives 1000 Wm^{-2} because of the pollutants and the molecules in the atmosphere. However, the output rate is low for solar PV, approximately 15 to 20 percent. As seen in Figure 1, companies like the national renewable energy laboratory (NREL) and SHARP can successfully produce panels with 47 percent efficiency, which means a meter squared of solar panels can produce around 500 Wh in an hour [1].

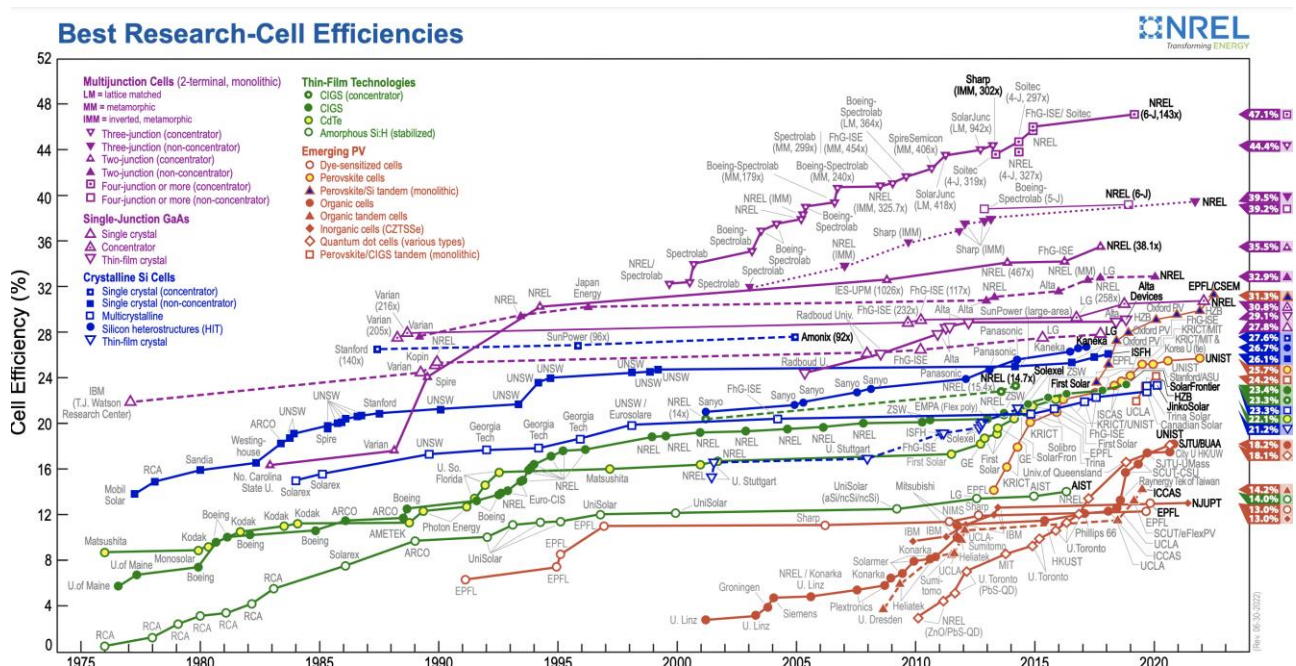


Figure 1. The efficiency of solar PV panels [1].

When talking about this being applied to aircraft, there are also benefits. Because solar UV rays increase with height in the atmosphere, the efficiency of solar panels is maximized at higher altitudes. Additionally, fewer air molecules, various pollutants, and other factors result. In addition, solar panels will receive more sunlight at higher altitudes; however, the temperature will be lower due to the colder conditions. Every degree Celsius taken off the panel's temperature resulted in a 0.05 percentage point increase in the panel's efficiency. Additionally, because more solar radiation is available at higher altitudes, it can generate energy more effectively. In addition, it is one of the best ways to achieve maximum output with a solar panel system, which can produce between 7 and 12 percent more power when placed on the ground [2, 3].

On the other hand, there are certain disadvantages, such as a reduction in the lifetime of solar panels due to their exposure to severe and extreme weather conditions at extraordinarily high elevations. Because of this, their life expectancy may decrease. However, even with this much energy produced, a square meter of the panel weighs about 20 kg on average. This indicates that if the panels are the only source that produces the energy, it will only be 40 watt-hours per kilogram, which is not enough to use solar panels alone to take off the plane, but gliding is still an option.

2.2. Power beaming

There are other additional options for power transfers, such as power beaming, which are also possible. Power beaming involves firing a laser into a receiver beneath the plane; the receiver then converts the beam of photon energy into electric power with relatively high efficiency. According to the research, the efficiency can be more than seventy percent, which is more than twice as high as a standard solar cell.

Numerous demonstrations of power beaming have been made over the years, using either microwaves or lasers, with the record for peak power being set in 1975. Researchers in the year 2021 were able to transmit the equivalent of 1000W across distances of more than a kilometer by using antennas [4]. Now, a tiny uncrewed power-beamed aircraft can fly outside of controlled zones in Japan without breaking any rules. As shown in Figure 2, the main components of this system are based on a ground-based transmitter, a receiver on the aircraft, and an airplane. A power source on the ground generates the microwave, which is transmitted by a transmitter antenna. The alternating current power is then changed into direct current by a receiver attached to the underside of one of the aircraft's main wings. The emphasis is sent from the antenna of the transmitter. Before the DC power is used to charge the battery, it first undergoes conversion by the DC/DC converter, which raises its voltage to an adequate level. The battery on the electric aircraft can receive a wireless charge, and that electricity is used to plane aircraft [5-7].

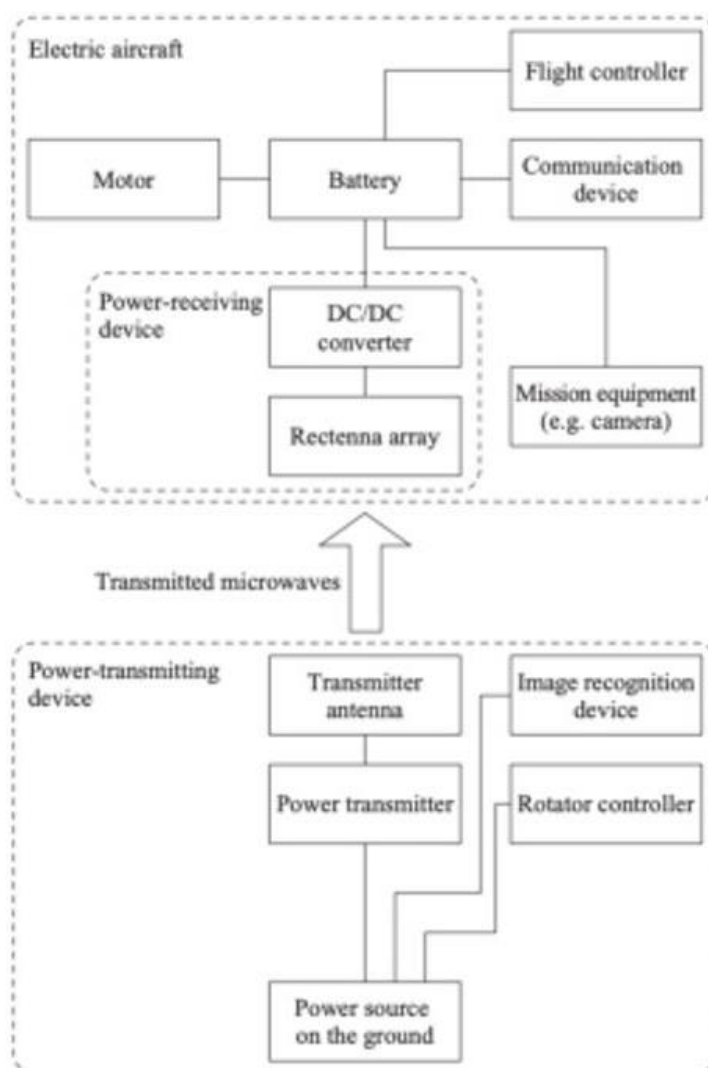


Figure 2. Configuration of power supply system [5].

3. Materials

3.1. Materials and benefits of cells

The electric aircraft battery NASA is studying has four cells, each with a lithium metal anode, a solid electrolyte, and an S cathode [8]. NASA plans to use new materials and construction methods to create a safer battery. The goal is to create a battery that is more Energetic than the lithium-ion batteries currently in use and could be used in electric aircraft. In addition, the battery will not reduce

capacity, catch fire, or endanger passengers when problems occur over time. Researchers at NASA are targeting new solid-state batteries for electric aircraft. An all-solid-state battery that does not contain any liquid can reduce packaging complexity, reduce safety risks, and withstand greater damage than a battery with liquid inside [9, 10]. The project uses elements that have never been combined before to form batteries. The project team investigated ways to use a unique combination of sulfur and selenium to hold a charge and found that solid-state sulfur-selenium batteries are good to the touch, do not ignite, are thinner, and store energy better than lithium-ion batteries. Although performance is reduced under non-ideal conditions, it can still operate. Another advantage is that the sulfur reserve is sufficient, and the Mass Loss Rate of the battery material without electrolyte is 0 at three radiation fluxes, indicating that the battery material will not burn. However, a battery material containing electrolyte will burn immediately upon encountering an ignition source, but the flame naturally extinguishes after the combustible material has burned out the electrolyte. The remaining battery material does not burn and otherwise changes except that the material becomes brittle to some extent. This indicates that the battery material's possibility of a fire being caused by the lithium-ion battery is very small. The characteristics of lithium-ion batteries are particularly important in low-temperature environments where the available energy and power degradation are more severe, and prolonged use in low-temperature environments will accelerate the aging of the power cell and shorten its life. Considering the complex operating environment of electric aircraft and the high safety requirements for ground power, a variety of cryogenic heating strategies need to be developed to improve the low-temperature performance of Li-ion batteries to ensure they can be discharged at low temperatures for normal use. Examples include phase change material preheating, heater preheating, DC preheating, AC preheating, and pulsed current preheating. High energy density lithium-sulfur battery is a type of battery that uses sulfur as the active substance in the cathode.

3.2. Li-S batteries

Inside, lithium-sulfur batteries theoretically have eight times the capacity of conventional lithium batteries of the same size. However, with low electrically conductive for the sandwich construction of the landing gear hatch, the main material choices for the panels are carbon fiber and glass fiber. High-modulus carbon fiber unidirectional tapes and preregs are more widely used. The core materials are honeycomb and foam cores, which need to be organically integrated with other materials, such as adhesives and foams, to provide sufficient strength and stiffness. According to the design guidelines issued by the Civil Aviation Authority of China and the US Federal Aviation Regulations, the hatch structure can stand a random hand or foot load of 1331.8 N in a downward direction; or a load of 666.6 N in any other direction. It is assumed that these loads act individually and are applied to any point on the door in any position from opening to closing.

4. Development and current difficulties of electric aircraft

4.1. New energy electric propulsion system

The electric propulsion system consists of the electric motor and the associated devices that provide thrust to the electric aircraft. The electric propulsion system is the heart of an electric aircraft. An electric aircraft's performance and application largely depend on its electric propulsion system. To enter the market, civil aircraft must obtain a license and airworthiness certificate from the civil aviation author. For jet general, utility, aerobatic and commuter aircraft with up to 10 seats or a gross take-off weight of up to 5670 kg, and for propeller general, utility, aerobatic or commuter aircraft with up to 19 seats or a gross take-off weight of up to 8618 kg, the aircraft should be designed and certified according to the C-23 or FAR-23 airworthiness standards. The Federal Aviation Administration (FAA) classifies light sport aircraft as land-based aircraft with a gross take-off weight of up to 600 kg and waterborne aircraft with a gross take-off weight of up to 650 kg, a maximum level flight airspeed of up to 122 km/h and a stall speed of up to 83 km/h, as single-seat and two-seat aircraft. The development of airworthiness standards for such aircraft is entrusted to the American

Society for Testing and Materials Standards (ASTM). Therefore, airworthiness certification for light sport aircraft is conducted in accordance with ccar-21 or far-21 and applicable ASTM standards. The electric propulsion units are normally designed and manufactured following ASTM f2840-11.

New energy is a broad concept that refers to all forms other than conventional energy, including solar, wind, biomass, geothermal, ocean, hydro, biomass, and hydrogen derived from renewable energy sources. Compared with traditional energy sources, new energy sources have the characteristics of less pollution, abundant reserves and even distribution. Electric aircraft's main new energy sources are batteries, fuel cells, solar cells, supercapacitors, and power beams. A storm is a device that generates electrical energy. There are diverse types of batteries. In the early days, the energy density of batteries was manually limited, so their use as propulsion power for aircraft was not easy. The main batteries that can be used in electric aircraft include lithium, air, and graphene batteries. Lithium batteries are divided into lithium-ion, graphene, and metal batteries. Lithium-ion batteries (with lithium-ion polymer batteries) contain no lithium in the mental state and can be charged and discharged. They are a proven product that can be used in electric aircraft. Their theoretical energy density is more important than 300 Whkg^{-1} . However, to prevent charging and explosive discharge, the energy density that can be safely used is currently $100\text{-}200 \text{ Whkg}^{-1}$, with a lifetime range of 500-2000 charging and discharging. There is room for further improvement.

Regarding energy density, other lithium batteries in the research phase (e.g., lithium-sulfur batteries) have much higher energy densities than current lithium-ion batteries. Air batteries mainly include zinc-air, lithium-air, aluminum-air, and magnesium-air batteries with energy densities of over 300 Whkg^{-1} . Domestically produced aluminum-air batteries have been tested in cars and will soon be used in aircraft Applications. However, unlike rechargeable batteries, aluminum-air batteries generate electricity by adding aluminum and changing the electrolyte. They are power-generating devices; the aluminum metal is processed using a unique machining process. "One minute to charge, 1,000 km to drive" gives the impression of a graphene battery. Although these batteries have a high energy density, theoretically, their application prospects are still controversial, and their use in aircraft has yet to be demonstrated.

A fuel cell is a power generation device that converts fuel energy into electrical energy. From the point of view of environmental protection, hydrogen fuel cells are mainly used in aircraft. Due to the low density of hydrogen and liquid hydrogen, hydrogen fuel storage requires large capacity or high-pressure containers, which limits its use as a power source for aircraft. In addition, hydrogen fuel cells have a high energy density but a low power density and are often used in combination with high-power-density lithium-ion batteries. The German Aerospace Centre (GAC) has installed a 90kw hydrogen fuel cell on the A320 to drive the aircraft's front wheels, enabling electric gliding on the ground without the aircraft's engines running, saving up to 15% in fuel consumption.

Figure 3 shows the mass-energy density e^* and the volumetric energy density V^* for batteries, hydrogen fuels and other fuels. Interestingly, lotions, creams and other 'biofuels' also have a higher energy density than batteries. Although no technology can convert them into electricity efficiently, it is not difficult to deduce that electric aircraft would not have the same range or durability as oil-engine aircraft.

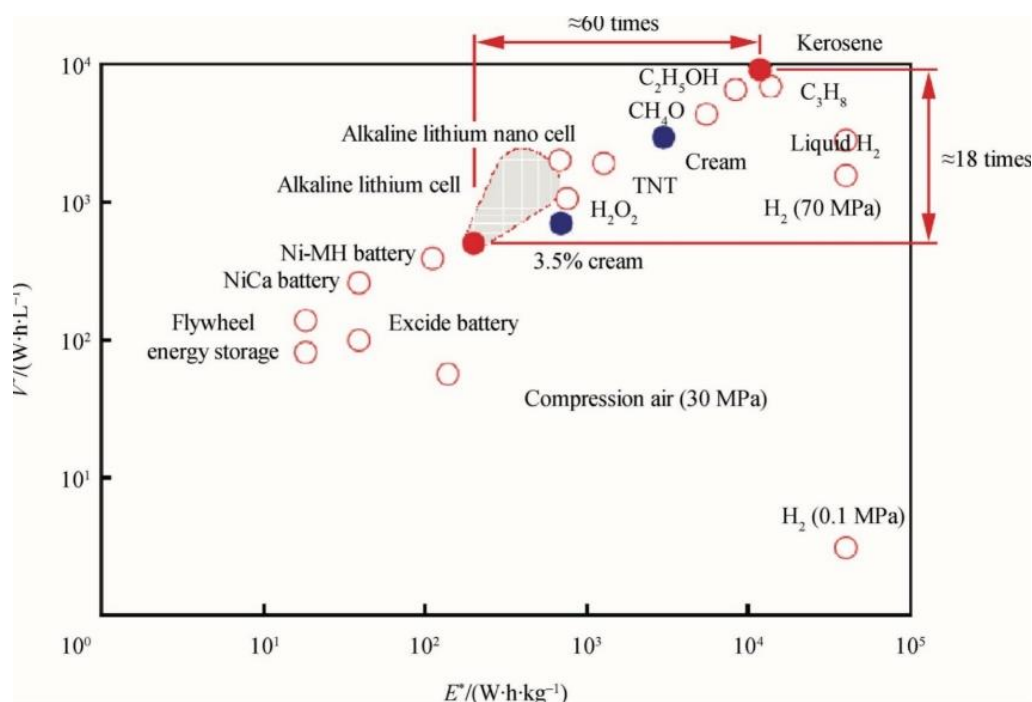


Figure 3. Mass Energy Graph [11].

A solar cell is a device that converts light energy into electrical energy through a photovoltaic effect or photochemical reaction. Currently, thin-film solar cells based on photovoltaic results are mainly used in aircraft. The photovoltaic conversion efficiency is the main representative indicator of solar cells. Among all solar cells, monocrystalline solar silicon cells have the highest photovoltaic conversion efficiency of 24%. Solar panels are laid on aircraft with large wing areas and low loads. The electrical energy obtained under illuminated conditions is sufficient to support the flight of a unique aircraft. However, the storage devices' energy density is insufficient to ensure flight at the same altitude at night. As a result, the practicality of solar-powered aircraft remains rather limited due to their small payload and poor maintenance.

Ultracapacitors are a unique power source between conventional capacitors and batteries, storing energy via a polarized electrolyte. The energy storage process is reversible and requires no chemical reaction, so it can be charged and discharged hundreds of thousands of times. It has a fast charge rate, high discharge capacity, high current, and high-power density. It is already used in electric vehicles and wind power generation and is expected to be used with fuel cells in aircraft. A power beam or wireless power transmission is a form of energy transfer that transmits electricity from a power source to an electrical device without solid wires or conductors. Energy can be transmitted by radiation, magnetic resonance, inductive coupling, and lasers. Although wireless power transfer is not a new concept, practical power beams are still in the preliminary stages of research, and their application in aircraft still has a long way to go.

4.2. Electric propulsion systems and their efficiency

The electric propulsion system of an electric aircraft is the series of components that generate electricity to overcome drag and move the aircraft forward, including the power source, controller, motor, gearbox, propeller, or ducted fan, as shown in Figure 4. The power source can be solar cells, fuel cells or batteries.

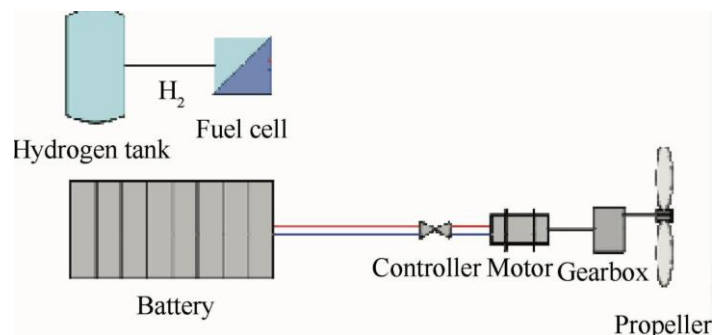


Figure 4. Battery system [12].

Propulsion system efficiency is the total efficiency of converting battery electrical energy into propeller pull or ducted fan thrust. In general, the efficiency of converting hydrogen to electricity via a fuel cell is about 60% and recycling solar cells into usable electrical energy is about 12%. Here, the propulsion system's efficiency is defined as the total efficiency of converting 100% of the battery energy into tension or thrust. If the controller efficiency is 98%, the motor efficiency is 95%, and the efficiency is 98%. With a propeller efficiency of 80%, the propulsion system efficiency is 73%. If no gearbox is used, the system efficiency can reach 75%.

5. Conclusion

In conclusion, there are many ways to provide energy supplies to airplanes. Nevertheless, these are all small skills not for commercial use, so there is a bright future for the electrified aircraft Industry. Also, this field has a lot more to develop, including the improvement in efficiency, long-term usage, and simplicity of the power supplying system. Although electric aircraft is only a tiny branch of the aircraft family, it is the main direction of Green Aviation Development and represents the future of aircraft development. However, soon, only electric aircraft with less than 19 seats are technically feasible so electric aircraft will be mainly used for general aviation.

The general aviation industry is an important economic growth point under China's new standard and a symbol of social maturity and progress. The development of China's general aviation industry can no longer follow the old road of "development pollution governance" of the automobile industry. It should vigorously develop available electric aircraft with the help of electric vehicles to control the negative impact of general aviation on the environment from the source.

New energy electric aircraft is one of the few fields in which China is developing at the same pace as the world's leading level. Caring for and supporting the progress of electric aircraft in technology, industry, and the market will help us to take advantage of our latecomer advantage, occupy the new technology field and industrial innovation highland of general aviation in the world, and improve our scientific and technological innovation ability.

Electric aircraft development is also faced with this challenge, and a series of key technologies need to be tackled: 1. the energy density, charge and discharge performance and cycle life of batteries need to be further improved; 2. The aerodynamic design technique with a high lift-drag ratio needs to continue to tap its potential and realize the refinement of analysis; 3. The low-cost, lightweight, and efficient composite structure needs to deepen the weight reduction optimization design under the constraints of safety and life; 4. Strive to improve the overall efficiency of the electric propulsion system. At present, the electric aircraft is the retrofit design of the traditional aircraft scheme, that is, replacing the fuel-consumed reciprocating power device with the electric propulsion power system without taking advantage of the scale-independent characteristics of the electric propulsion system. Comprehending and designing the distributed electric propulsion system and the aircraft's aerodynamic character is a research and development director with great technical potential.

References

- [1] A. Han. Efficiency of solar photovoltaic, then, now and future. Dec 2014 [Online; posted Dec 2014].
- [2] P. Jaffe. Practical power beaming gets real. May 2022 [Online; posted May 2022].
- [3] S. Luntz. How solar at high altitudes could power entire countries, even in winter. January 2019 [Online; posted Jan 2019].
- [4] S. Murmson. Does a solar panel stop working when it gets too cold? April 2017 [Online; posted April 2017].
- [5] O. Yuichiro. Study of electric aircraft charged by beamed microwave power. Vol.48, 2015 [Online; posted 2015].
- [6] SALANM A. EUNUS 2 I. Recent green aviation technologies an overview, Journal of Modern Science and Technology, 2013, 1 (1): 61 - 75.
- [7] AIRBUS. Global market forecast 2015-2034. (2015-02-01), <http://www.airbus.com/company/market/forecast>.
- [8] HYDER A K. A century of aerospace electrical power technology. Journal of Propulsion and Power, 2003, 19 (6): 1155 – 1179.
- [9] AKATAS D. General aviation electric-powered aircraft feasibility: AIAA-2012-1040. RI. Reston AIAA, 2012.
- [10] TAKAHASHI K. FUTIMOTO H, HORI Y. Modeling of propeller electric airplane and thrust control using advantage of electric motor, IEEE International Workshop on Advanced Motion Control. Piscataway, NJ: IEEE Press, 2014: 482 - 487.
- [11] STEINER H, VRATNY PC C, GOLOGAN C, et al. Optimum number of engines for transport aircraft employing electrically powered distributed propulsion J. CEAS Aeronautical Journal, 2015, 5 (2): 157 - 170.
- [12] ASTM. F2840-11 Standard practice for design and manufacture of electric propulsion units for light sport aircraft, New York: ASTM International, 2011.