

The Development Status and Key Technologies of Solar Powered Unmanned Air Vehicle

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Abstract. By analyzing the development status of several typical solar powered unmanned aerial vehicles (UAV) at home and abroad, the key technologies involved in the design and manufacture of solar powered UAV and the technical difficulties need to be solved at present are obtained. It is pointed out that with the improvement of energy system efficiency, advanced aerodynamic configuration design, realization of high applicability flight stability and control system, breakthrough of efficient propulsion system, the application prospect of solar powered UAV will be more extensive.

1. Introduction

Solar powered UAV is a kind of aircraft based on solar radiation as a propulsion energy. During the solar powered UAV flight, the solar energy cell array converts the solar energy into DC output, then the Maximum Power Point Tracker(MPPT) controls the maximum output power of the solar cell and converges to the main power supply circuit. The power control device sends the power to the motor-propeller system. Solar radiation is the total energy source of UAV. During the daytime, solar radiation can be converted to electrical energy. The energy maintain power plants and airborne electronic equipment's work, and support the aircraft climbed to a certain height, also charge the energy storage system. At night, energy storage system release the stored energy, maintain the entire system of the normal operation. The aircraft gradually reduce to a certain height, by optimize the track to reduce the energy consumption of energy storage system[1]. If the energy absorbed during the daytime can meet the needs of the whole day flight, solar powered UAV can achieve uninterrupted flight day and night theoretically[2].

Solar powered UAV's prospects are very broad as solar radiation is a clean and renewable energy. Solar powered UAV can be used for communication relay, reconnaissance, surveillance, electronic countermeasures and so on as it can not consume energy, do not have to take off and land maintenance, can be sustained at high altitude flight. Google's Sky Bender project also plans to use solar unmanned aerial vehicle transmission 5G network, and in the future it may also achieve commercial manned flight. Many countries are in the relevant technology research as the solar aircraft has so many advantages.

2. Development status

2.1. Development status of foreign solar powered unmanned aerial vehicles

In November 4, 1974, Sunrise I successful maiden flight mark the first step in human solar flight unmanned aircraft [3]. Although Sunrise I is based on glider technology, advanced UAV design



technology embodies less, but opened the door of solar flight. Solar powered UAV finally embarked on the rapid development of express Road with the solar cell conversion more efficiency, energy storage system energy density increasing, wide development and application in aircraft design technology, automatic control technology, microelectronics, new materials technology and so on [4].

2.1.1. "Helios" UAV. "Helios" UAV, developed by NASA and the Aeronautical Environment Corporation (UAS), use a large aspect ratio (31) wing layout to improve aerodynamic efficiency and is designed centre on the utilization of solar energy(as show in Figure 1). Wingspan 75.3m, area 183.6m², with 62120 pieces of solar cells, can provide 40 kilowatts of power, driving 14 propellers flight, high-altitude model weight 720kg, long-time model weight 1053kg. In August 2001, the high-altitude model hit a record of 29,524 miter, it was the highest propeller-driven UAV in the world that time [5-7].



Figure 1 " Helios " UAV



Figure 2 " Zephyr 7"UAV

2.1.2. "Zephyr 7" UAV. "Zephyr 7" UAV is designed by the United Kingdom Qinetiq Company. A large number of carbon fiber composite materials used in the solar powered UAV, and is the embodiment of the top technology of solar aircraft(as show in Figure 2). During the day, it use a thin film amorphous silicon thin-film batteries to absorb solar power to cruise at 18km high, at night it flight by the lithium-polymer battery witch energy is 2 times of the lithium-sulfur batteries [8]. In order to save energy, it glide down with dynamic. The wingspan is about 22.5m, total mass is 53kg, it has the lightest structure density in the unmanned aerial vehicles (0.8kg / m²). In July 2010, 336 hours of continuous flight at 21.6km, creating a new UAV continuous flight time. Airbus said in a statement, the first "Zephyr" -8 UAV has been under construction, and will begin first flight in mid-2017 maiden voyage.

2.1.3. "Condor" unmanned aerial vehicle project. "Condor" UAV project proposed by the US Defense Advanced Research Projects Agency, the target aircraft flight height is 18 ~ 27km, sustained flight time 5 years, rated power 5kW, the payload can carry 450kg. If successful, will become the world's most advanced large-capacity high-altitude permanent flying solar unmanned aerial vehicles. The first phase of the project is the Aurora's Odyssey, Boeing's Solar Hawk and Loma's Norma, as shown in Figures 3, 4 and 5. September 2010, "Condor" project using the "Solar Hawk" program, developed by Boeing using solar / power-driven unmanned aerial vehicle prototype. Boeing said the "Sun Hawk" program will continue flight of about 30 days of the first flight in 2014 to verification the power systems and structures and other key technologies. It is still in the validation phase, and there is no real load-carrying flight.

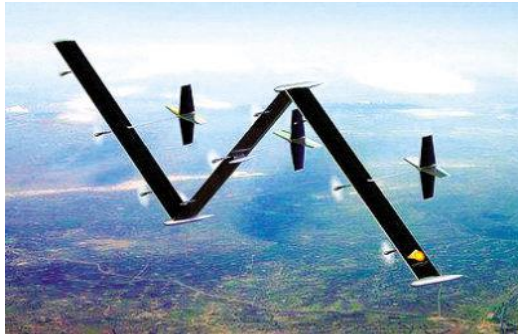


Figure 3 Aurora "Odysseus" UAV program



Figure 4 Loma's "Norma" UAV program



Figure 5 "Solar Hawk" UAV program



Figure 6 "Solar Impulse 2" solar aircraft

2.1.4. "Solar Impulse 2" solar aircraft. "Solar Impulse 2" solar aircraft is designed by the sun team of high-altitude long-endurance manned aircraft, whoosh's flight required energy entirely from solar cells. A large number of new carbon fiber composite materials are used in the aircraft's manufacture (as show in Figure 6). The wingspan is 72 meters, weighing about 2300kg, the aircraft installed 17,248 thickness of only 135 micron monocrystalline silicon solar panels, can produce 340 kilowatt hours of electricity per day, driving four power 13.5 kilowatts of DC brushless, no Sense of engine work and charge 633 kg of lithium-ion battery. Beijing time March 9, 2015 to April 23, 2016 evening, "Solar Impulse 2" solar aircraft from the UAE capital Abu Dhabi departure, divided into eight sections of the Genesis manned world flight, and created the longest Distance single-person flight records. During the overheating of the battery problem, rest for 10 months. Local time at 4:00 on July 26, 2016 "Solar Impulse 2" successfully landed in Abu Dhabi.

2.2. Development status of domestic solar powered unmanned aerial vehicles

After years of exploration and practice of China's solar energy application technology, mobile power storage, advanced aircraft design, modern control technology and advanced aviation composite materials, a certain foundation for China's independent research and development in solar unmanned aerial vehicles to provide a guarantee. However, we are still at the initial stage from the development of the field point of view.

2.2.1. "Soarer" UAV. "Soarer" UAV is China's first solar aircraft, design and manufacture by Dr. Li Xiaoyang and Professor Zhao Yong in 1992 (as show in Figure 7). It is the first aircraft with original intellectual property rights of solar energy aircraft in the history of China. "Soarer" UAV's body and the wing using carbon fiber and Kevlar, balsa and other materials, the upper wing and horizontal tail are laid monocrystalline silicon solar cell sheet. The energy storage system is the nickel-metal hydride battery pack, propulsion system is a slow speed propeller. "Soarer" UAV's flight establish theoretical basis and accumulated experience in engineering practice of develop practical solar energy aircraft.



Figure 7 "Soarer" solar aircraft



Figure 8 "Green Pioneer I" verification machine

2.2.2. *"Green Pioneer I" solar aircraft.* "Green Pioneer I" solar aircraft is the green pioneer program's first generation of sample machine(as show in Figure 8). "Green Pioneer I" uses a layout and structure of new and reasonable composite flying wing aerodynamic layout. The whole machine, the lower wing surface set up a high conversion rate of flexible solar arrays as a power and control, task equipment, energy collectors. "Green Pioneer I" wind tunnel experiments and field flight experiments show that China's composite wing program than the current layout of other forms of advantage, is China's solar energy aircraft design a major initiative.



Figure 9 "Rainbow" solar powered UAV

2.2.3. *"Rainbow" solar unmanned aerial vehicles.* "Rainbow" solar powered UAV successfully test flight on May 22, 2015(as show in Figure 9). The solar unmanned aerial vehicle using large aspect ratio and lightweight structure, wingspan 40 meters, is the world's largest solar unmanned aerial vehicle following the United States NASA series. The success of the pilot opened a new chapter in China's solar unmanned aerial vehicle exploration.

At present, there has not a company can really realize the practical requirements of solar powered unmanned aerial vehicles, both solar power, long time alternating flight day and night, across the season and has a greater load capacity. Solar powered UAV research and development, there is still a long way to go. It is not only the focus of China's aviation industry in the new century, but also a new hot spot of national aviation industry research.

3. Key technologies and development trends

3.1. Energy system

From the solar panel to receive solar radiation, power system output power driving the aircraft flight, the efficiency of the entire system is only about 10%.

At present, most solar aircraft power generation systems are silicon-based solar cells and compound solar cells. The most widely used monocrystalline silicon panels have high photoelectric conversion efficiency (15% -20%), but the structure quality is high. Amorphous silicon a-Si thin film solar cells as an alternative of monocrystalline silicon, the current conversion efficiency increased to 12% or more. Gallium arsenide (GaAs) solar cells have a higher conversion efficiency than silicon cells (43% theoretical efficiency, 28% efficiency), but expensive. Copper indium selenide (CIS) thin film solar cells also have great research value [8]. In addition, the solar aircraft on the laying of solar cell technology is also need to study. High altitude weather conditions are complex, the temperature difference between day and night changes, and the solar radiation intensity, require solar cells have good physical properties and high reliability. Solar cell is very thin, subject to greater external force will be severely damaged, requiring the wing can not have too much deformation. In addition, a large number of large solar UAV joints, will reduce the reliability of the circuit see the connection [4], its layout will also affect the efficiency of solar energy conversion [9][10].

Energy storage system is a very important part of solar powered unmanned aerial vehicles. At present, lithium batteries are widely used in solar airplanes, and some large-scale high-altitude solar airplanes use large-scale lithium ion batteries, lithium sulfur batteries ("Zephyr 7" UAV), fuel cells ("Helios" UAV). The weight of the energy storage system is generally 30% -50% of the total weight of the machine, which has a great impact in the ultimate aerodynamic layout and geometry of the UAV. The research of secondary battery with higher energy density, safety, reliability, cycle number and cheap price has become an important content of solar aircraft research. July 8, 2016, the world's first graphene lithium-ion battery was officially released, greatly enhancing the lithium-ion battery's applications.

During solar flight, the flight time, height, speed and attitude are constantly changing. The solar radiation intensity and temperature are also changing, which causes the open circuit voltage, short circuit current and maximum power of the solar cell to change [11][12]. The main function of the power control subsystem is to monitor the energy demand of each unit in real time and to allocate energy reasonably and efficiently. Today, MPPT controllers are widely used. It can match the input current of the solar cell and the current output to the load to achieve the maximum power output to achieve the best utilization of energy. According to the relevant units of the actual test, the use of MPPT controller power generation system than the traditional efficiency by 20% [13].

In summary, the future development trend of solar energy systems for unmanned aircraft is that: (1) improve the quality of silicon solar cell conversion efficiency and specific power; (2) new types of thin film solar cells, reduce quality, reduce costs, improve the conversion efficiency; (3) form of the solar cell module layout, layout, technology and mechanical characteristics, environmental characteristics, improve the applicability of the solar cell on the UAV; (4) improve the storage battery energy security and higher research and development security, better performance such as lithium polymer batteries, lithium - sulfur batteries, lithium-air batteries; (5) to carry out a more lightweight, efficient, safe, renewable fuel cell technology; (6) research and development of more powerful and efficient reliable intelligent power control system.

3.2. Overall integrated design technology

Solar powered UAV, which have a low Reynolds number are relatively small (about 10^5 - 10^6) in comparison with the Reynolds number, due to the high altitude flight of thin air. In order to obtain good lift characteristics, general solar aircraft have a large aspect ratio, in order to reduce the weight, carbon fiber, Kevlar and other advanced composites are widely used. At present, due to the unique parameters of solar aircraft, the conventional design method is difficult to meet the design requirements. Therefore, in the process of determining the overall parameters of solar aircraft, the energy balance should be integrated to optimize the efficiency, integration of subsystems, and system

efficiency [14]. In addition, the integration of Multidisciplinary Design Optimization (MDO) is also a hot research [19].

At low Reynolds number, the separation and transition of solar UAV surface flow are sensitive to Reynolds number, pressure gradient and flow condition. Laminar flow separation occurs at the leading edge of the airfoil, and the boundary layer flows into turbulence to form a laminar separation bubble structure, which affects the aerodynamic characteristics of the airfoil. Due to the presence of laminar and turbulent flows in the wing surface, the state of the boundary layer must be improved to improve aircraft performance. Long flight UAV special flight conditions, the conventional airfoil is difficult to meet, so the airfoil must be designed for its doors. Good lateral and longitudinal stability is an important condition for maintaining high-altitude flight for a long time, and must be taken into consideration when carrying out integrated design. The traditional aerodynamic layout is relatively mature, the technical risk is low, but in the low-speed low Reynolds number flight conditions, there are obvious problems of aerodynamic efficiency, so there are aircraft flying wing and other new aerodynamic layout. Large aspect ratio wings (about 30) enhance the aerodynamic efficiency, but also brings the problem of aeroelasticity, affecting the stability and safety of aircraft, need to be considered.

At present, light non-metallic materials because of its unique performance, in the application of solar UAV more carbon fiber composite materials because of its high strength characteristics of lightweight, multi-do for the load-bearing structure. Large aspect ratio and soft wings, will lead to unmanned aerial aircraft flying wing has a considerable deformation, and large deformation will cause changes in aerodynamic loads. This kind of aerodynamic / structural coupling makes the UAV have aero elastic problems, so that the flight quality of UAV will be affected, and even stability and security problems will be brought [22]. To improve the reliability of the system, the use of distributed propulsion system, propeller slip flow and aerodynamic interference of the wing is a difficult and difficult problem in the design of aircraft[25][26] The research of propeller wing Slip flow influence on the design of UAV aerodynamic layout has important significance.

3.3. Flight stability and control technology

The influence of the distributed propeller on the flight quality of the wing is more complicated. The flight stabilization and control module design is required for the solar powered unmanned aerial vehicle (UAV) to be subjected to aerodynamic forces during the flight, which results in great nonlinear deformation. Has brought a lot of restrictions, the conventional control law has not a very good solution to the problem. The effect of aeroelasticity on the flight control mode needs to be addressed. Power control subsystem and flight control system coordination, but also need to be addressed.

Due to the low flying speed of the UAV, low propeller speed, low power of the propulsion system, large aspect ratio of the wings and the distribution of the multiple propellers along the wings, the distributed propulsion system of the solar unmanned aerial vehicle Characteristics have a greater role, especially on the horizontal flight quality to bring a non-negligible impact [27]. Multiple-oars bring more options for heading control, and how to optimize the heading control without affecting the long life time is also a key problem worthy of study. There are two main problems in the design of thrust control and distribution system for solar unmanned aerial vehicle (UAV): (1) To improve the energy efficiency of the whole system on the basis of providing thrust and yaw moment required by the aircraft; (2) And the attenuation and hysteresis due to the slow dynamic characteristics of the propulsion system [28]. Stepanyan proposed a differential thrust adaptive control method in the case of a vertical tail fault[29]. Chen Huai-min, Wang Rui, and Zhu Xiaoping et al. Have studied propeller differential thrust to realize the solar-powered unmanned aerial vehicle heading control problem. Sun Chengxiao studied the pitch control method of multi-propeller solar unmanned aerial vehicle , and pointed out that the multi-propeller control realized by the change of motor speed could make the solar unmanned aerial vehicle satisfy the requirement of long flight time. Research and development to adapt to high-altitude long-endurance flight of unmanned aerial vehicles flying characteristics of the flight control system is the development of solar energy UAV key technology.

3.4. Propulsion system

For solar unmanned aerial vehicles, the propulsion system generally uses a motor-driven propeller approach. Direct-drive distributed propulsion systems are used in solar aircraft, and only in small solar-powered aircraft to reduce the drive to improve propeller efficiency. Solar unmanned aerial vehicle energy system output is DC, in order to reduce the conversion equipment and aircraft weight, should be preferred DC motor. The ordinary brush DC motor brush and commutation brush because of the existence of easy to produce sparks, and in high altitude conditions, heat dissipation performance is poor, poor reliability. Brushless DC motor can replace the brushless commutator drive circuit and commutator, fast response, large starting torque, and has the self-cooling effect, but the need to increase the DC - AC inverter, the circuit is more complex. Rare-earth permanent magnet brushless DC motor with high efficiency and less moving parts has been widely used in solar unmanned aerial vehicles (UAV), but its control is complex and expensive. Long-time solar unmanned aerial vehicles to reduce the moving parts, the use of more fixed-propeller. This also brings a certain problem: low-altitude characteristics of a good propeller, often at high altitude can not adapt to reduce the efficiency of different Reynolds number, the efficiency of change. The use of variable-propeller propeller to improve the adaptability of the UAV to maintain a high propulsion efficiency, but will increase the overall weight.

From the above analysis, the high-altitude long-term development of solar unmanned aerial vehicles can not be separated from its propulsion system of technological breakthroughs. One is to ensure the high-power torque characteristics of the drive motor, to improve the efficiency of the motor under the premise of reducing its size and weight; the second is to break the propeller and the high efficiency of the motor drive matching problem, research and development of efficient, Of the pitch-propeller, reducing costs and weight.

4. Conclusion

Since the first solar-powered aircraft first flight in November 1974, with the advancement of technology, mankind has realized the long flight of manned space flight. We believe that in the near future, with the solar cell conversion efficiency, energy storage system power density and propulsion system efficiency, and advanced aircraft design technology, automatic control technology, microelectronics technology, new materials technology development and application, the real The meaning of the permanent flight will be able to achieve, riding the sun will no longer be a dream flight.

5. References

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