Structural Design and Difficulties of Solar UAV

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Structural Design and Difficulties of Solar UAV

W W Zhang[1,a], L G Zhang[2,b], Z W Yan[1] and L Wang[1]
[1] School of Aerospace Engineering, Shenyang Aerospace University, Shenyang, China
[2] General aviation research institute, Shenyang Aerospace University, Shenyang, China

E-mail: [a]zww13579@163.com; [b]1183590317@qq.com

Abstract: The design of high-altitude and long-endurance solar aircraft is obviously different from that of conventional aircraft. Its unique energy system and operating conditions make it necessary to carefully weigh the key technical details in design. The structure has a great influence on the endurance performance of solar aircraft. The structure weight can be roughly estimated by the proportion of the airborne energy system to the total weight of the aircraft, so as to optimize the structure. Through the analysis of several typical solar aircraft, it can be concluded that the aerodynamic layout and structure design have a great impact on the flight time and performance of solar aircraft. Finally, the challenges faced by solar aircraft are presented, which can provide reference for the design of solar aircraft in the future and help.

1. Introduction

With the continuous consumption of renewable resources and the increasing global warming, most countries begin to focus on non-renewable Green Resources solar energy. Since 1981, when the United States developed the first solar unmanned aerial vehicle, Solar Challenger, many countries have begun to invest a lot of energy in solar unmanned aerial vehicles. Compared with traditional UAVs, solar UAVs have the advantages of environmental protection, high flight altitude, strong stability, wide coverage area and outstanding load capacity. While solar-powered UAV has many advantages, it also faces great difficulties in design, especially in the two aspects of too large force on wing root and too large deformation of wing root. Excessive force on wing root will cause material failure of wing root beam, while too large deformation of wing will cause aerodynamic performance degradation of wing and damage battery, which will affect the endurance of aircraft [1].

In addition to the conversion efficiency of solar cells, the aerodynamic layout of solar UAV also has a great impact on it. There are many aerodynamic layout forms suitable for solar UAV, such as conventional layout, flying wing layout, double strut layout, tandem wing layout, V-tail layout, etc. Each layout has its own characteristics. In order to solve the problems of large aspect ratio wing deformation, flight control difficulties and aeroelasticity, most of the solar UAVs in recent years adopt conventional layout [2].

2. Proportion of airborne energy systems

In the design of solar UAV, according to its mission requirements, the total weight, flight speed, lift-drag ratio of UAV can be determined first, and then the weight of storage battery and solar cell can be calculated. From the design principle of solar aircraft, the weight ratio of each part can be calculated.

The weight ratio of energy storage battery is:

$$\frac{Q_b}{Q_j} = \frac{\left(\frac{Q_j vg}{k\eta_m\eta_B q}\right)t(1+k_b)}{Q_J} = \frac{vg(1+k_b)}{k\eta_m\eta_B q}t \tag{1}$$

Weight ratio of solar cells:

$$\frac{Q_s}{Q_j} = \frac{S_s q_s}{Q_j} = \frac{W_s\frac{\pi q_s}{p_s\eta_s(24-t)}}{Q_j} = \frac{p\left(\frac{t}{\eta_c}+24-t\right)\pi q_s}{p_s\eta_s(24-t)Q_j}(1+k_b) = \frac{vg\left(\frac{t}{\eta_c}+24-t\right)\pi q_s}{k\eta_m\eta_B p_s\eta_s(24-t)}(1+k_b) \tag{2}$$

In the formula, Q_j is the total weight of UAV; Q_b is the weight of storage battery; v is the flight speed; k is the lift-drag ratio; η_m is the efficiency of motor; η_B is the efficiency of propeller; η_s is the efficiency of solar cell; η_c is the efficiency of charging and discharging of storage battery; q is the density of storage energy and p_s is the density of solar energy.

When the total weight of the solar UAV, the weight of the storage battery and the weight of the solar panels are all determined, if the weight of the aircraft needs to be increased, the structure of the aircraft can only be improved. The best structure of the aircraft can meet the requirements of strength and stiffness and achieve the minimum quality. For the solar UAV, in order to meet its long-term performance, it usually has a large area of solar cells in the design to meet the energy storage of the solar UAV during day and night flight. At the same time, it uses the form of large aspect ratio to reduce the induced drag of the aircraft and improve its lift-drag ratio. The wing of the aircraft is usually designed relatively large, and the weight increases accordingly. Therefore, the design of the structure is particularly important.

3. Structural Analysis of Several Solar Unmanned Aerial Vehicles

3.1 "Helios" Series Solar UAV

"Helios" series solar UAV is a solar UAV developed by the United States. It has gone through five stages, namely "Pathfinder", "Pathfinder+", "centurion", "HP01" and "HP03"[3]. HP03 solar UAV has a main pod, four sub-pods, two hydrogen storage and 14 motors. Its wingspan is 75.3m, chord length is 2.44m, wing area is 183.6m^2, and the outer wings on both sides have a 10 degree up angle. "HP03" solar UAV adopts flying-wing configuration, the main reasons are as follows: 1. Flying-wing aircraft are not prone to nose-down dive; 2. Wings will not have the tendency of backward bending; 3. Flying-wing configuration has better balance and operational stability; 4. Its resistance is small, wing load is low, the available space in the wing is large, and the load is large, which is beneficial to large aircraft.

Figure 1. "HP03" Solar UAV.

"Helios" series solar UAV adopts the structural form of strong beam and weak wall. Its wing and fuselage are mostly made of composite materials, such as Karaff, Omez, carbon fibers, etc. and high-quality film diaphragm is used as the wing skin. In order to reduce the weight of the wing, holes are arranged on the wing ribs according to the design requirements. The extensive use of composite materials makes the wing flexible and can prevent the wing from breaking during flight. The elastic deformation of the wing is very large. In normal flight, the wing bends upward under the action of aerodynamic force, and the tip of the wing warps up to 4.5m. There are 72 lifts on the trailing edge of the wing, which increases the maneuverability of the aircraft. When turning, it is mainly realized by changing the pull force of four motors on the left and right sides. There are several streamlined flat pods under the wing, which have three main functions: one is to install wheels as landing gear; the other is to load task modules inside; and the third is to play the role of directional stability, as shown in Figure 1.

The HP03 solar UAV trembled for a long time at low altitude, which eventually led to the crash of the unmanned aerial vehicle. The reasons are as follows: first, after modification, 14 motors are reduced to 10 motors. The propellers driven by these 10 motors are scattered over the whole wingspan. When the wing is bent upward by a large margin, the pulling force of the propeller in the outer wing will produce a large downward pitching moment. When the wing bending decreases, the downward pitching moment of the wing decreases sharply, the oscillation of the wing bending and the change of the pitching moment of the wing. The second is that the torsion center of the wing is behind the aerodynamic center of the wing, and when the wing oscillates up and down, the torsion of the wing strengthens and the material fails. Despite the crash of the HP03 solar UAV during its second flight, it is still one of the successful examples of structural design.

3.2 "Solar Impulse 2" Solar Aircraft

The "Solar Impulse 2" aircraft developed by Swiss Solar Impulse Company adopts the conventional layout, the outer wing section is upside down, the fuselage is in the form of short bunker and tail beam, the front fuselage is in the cockpit, and the back half fuselage is triangular fuselage, which makes the fuselage more stable and has better torsion resistance as shown in Figure 2. The wing is 72m long and 2300kg in weight. There are 17 248 high efficiency solar panels installed on the wing surface. In wing design, there is one rib per 50cm, 144 ribs are arranged on the whole wing, and the effective battery installation area of the wing is 270 m^2. In order to reduce weight, the battery is directly designed as part of the wing, instead of installing the battery on the wing. Four pods are installed on the lower surface of the wing to install motors, propellers and lithium batteries.

Figure 2. "Solar Impulse 2" Solar Aircraft.

The "Solar Impulse 2" aircraft uses light weight and strong load materials such as carbon fiber and foam. Because the cabin is used for pilot driving, the thermal insulation material is used on the cabin to prevent the damage caused by the low temperature at high altitude. Polyurethane foam used in some parts of cockpit shell. In the design of door locks and porthole, the aircraft uses polyurethane composite material, and some polyurethane foam outside the cockpit is used for battery insulation. At the same time, the body is also covered with silver coated raw materials, which can protect solar cell [4].

3.3 "Green Pioneer" Solar UAV

The "Green Pioneer" solar UAV adopts the "composite wing" aerodynamic layout, which integrates the combined wing and tailless layout skillfully. It not only makes the structure of the aircraft more compact and lighter, but also greatly reduces the energy consumption, but also increases the aerodynamic characteristics of the wing. It has a wingspan of 7.5 m, a captain of 2.84 m and a cruise altitude of 5000m. It is powered by six small DC motors.

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"Green Pioneer" adopted the "composite wing" layout, which is the first aerodynamic layout form in the world[5]. This structure can arrange solar panels on the upper and lower wing surfaces. The upper wing surface can receive solar radiation directly, and the lower wing surface can receive sunlight reflected by clouds and atmospheric particles, thus greatly increasing the area of solar radiation, as shown in Figure 3. Show. The layout of "composite wing" makes the load-bearing route of the whole aircraft structure shortest, reduces the weight needed to ensure the structural strength, and can effectively reduce energy consumption and increase useful load.

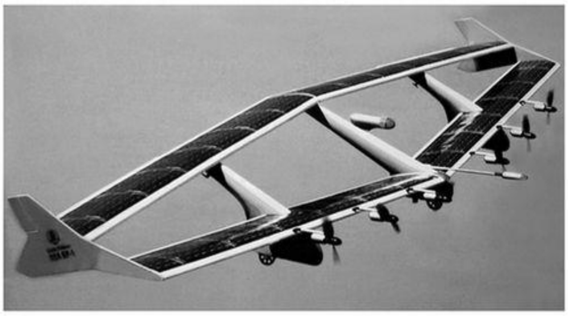

Figure 3. "Green Pioneer" Solar UAV.

3.4 "MY-6" Solar UAV

"MY-6" UAV is a long-endurance solar UAV developed by Northwest Polytechnic University. The whole fuselage is 1.2m long and the wingspan is 7m. The weight of the UAV is only 15kg, the maximum mission load is 5kg, and the flight altitude is 6,000 m. The duration in summer is 23 hours, while in winter it is 13 hours because of the weak sunshine. The aircraft adopts full-wing pneumatic layout, has ultra-light surface density structure, and has high efficiency of laying solar panels. The structure of aileron and spoiler is not designed on the wing, which can effectively increase the laying area of solar panels; the fuselage is designed as a large airfoil shape, so that the fuselage can generate part of lift and reduce energy consumption during flight; there is a vertical tail at each side of the fuselage and at the rear of the wing, which can play the role of the stabilizer; at the front edge of the left and right wings, there is a vertical tail at each side of the fuselage. There is a motor to power the UAV. The turning of UAV is mainly realized by differential rotation of the motors on both sides. There is an elevator at the tail of the fuselage, as shown in Figure 4. The connection between the wing and the fuselage is carbon pipe plug-and-pull, and the wing beam is carbon pipe. In terms of material, the whole aircraft is made of carbon fiber, which makes the aircraft have high strength, stiffness and light weight at the same time.

Figure 4. "MY-6" Solar UAV.

4. Major Challenges for Solar UAV

4.1 Energy System

Energy system is one of the key technologies in the design of solar UAV, which includes energy storage system, solar array and energy management and distribution system [6]. In order to improve the performance of solar UAV, we can make breakthroughs in two aspects. On the one hand, we can improve the performance of a single panel, improve its energy conversion rate and reduce its weight. In the whole energy conversion process, except the conversion efficiency of solar cells is about 20%, the conversion efficiency of other parts is more than 70%[7]. As far as the current solar panels are concerned, they can be roughly divided into two categories: crystalline silicon solar cells and thin film solar cells. Most of the existing solar UAVs use crystalline silicon solar cells. With the development of solar cells, the thickness of crystalline silicon solar cells becomes thinner and lighter, but the welding process will also result in larger fragmentation rate. Although gallium arsenide thin film battery has high conversion efficiency and good radiation resistance, its application is limited to a large extent due to its high cost. On the other hand, better battery packaging technology is used to reduce energy loss. Because solar panels are brittle, the brittleness, impact resistance and disassembly of solar cells must be taken into account in battery packaging. The laying of solar array should take into account the deformation of the wing during flight, and adopt the layout form which is suitable for the bending of the wing. Therefore, improving the efficiency of energy system can effectively increase the flight time of solar UAV.

4.2 Structure Design and Pneumatic Layout

Most of the solar UAVs designed at this stage only achieve the long-range goals, but the load is not outstanding, and the maximum load is only tens of kilograms. Therefore, reasonable structure design and aerodynamic layout are particularly important. A good design can greatly increase the load of UAV. At present, almost all solar UAVs adopt super-large aspect ratio mechanism, which will inevitably cause large deflection deformation during flight, which will cause very prominent aeroelastic problems. Therefore, in structural design, in addition to ensuring strength requirements, it should also ensure sufficient stiffness. Selection of light-weight and high-strength structural materials, rational structural layout design and fine processing of light and thin structural parts are important structural and technical problems that solar UAV must solve. At present, the aeroelastic calculation and analysis methods in the aviation field are not suitable for the non-linear aeroelastic problem of solar UAV. Therefore, new aeroelastic theories and methods must be developed.

4.3 Flight Control Technology

Flight control technology is also one of the problems to be solved urgently, especially in the case of low-speed flight, the wing flutter caused by long-span flight altitude and the aeroelastic control of flexible wings. When the aircraft crosses the troposphere, it is easy to encounter gusts and atmospheric turbulence, which will cause wing tremor and cause aircraft disintegration. For example, “HP03” solar unmanned aerial vehicle is disintegrated and crashed in this situation.

5. Concluding remarks

Solar UAV has remarkable performance and broad development prospects. It is widely used in military and civilian fields. At present, many countries regard it as the existence of sub-satellite for weather prediction, reconnaissance and so on. Despite the continuous progress of science and technology, there are still many difficulties to overcome. From the structural analysis of the solar unmanned aerial vehicle which is more famous at home and abroad, it can be seen that the structural design can improve its performance to a great extent. Therefore, if there is a breakthrough in the aerodynamic layout and structure design, the development of solar UAV will enter a stage of rapid development.

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