The Development of Atmospheric Geo-stationary Platform by Solar UAS

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ABSTRACT:

The preliminary study of the so-called atmospheric geo-stationary platform has been initiated by National Space Organization (NSPO) of National Applied Research Laboratories (NARL), the Republic of China (ROC) since 2014. Among all candidates, the solar-powered aircraft was selected as a high altitude platform to conduct various experiments. Therefore, this paper illustrates systems engineering aspects of the solar unmanned aircraft system (UAS) to conduct the experiments which altitude is below 10 km and time duration is above 8 hours. The power consumption will be calculated using flexible thin-film solar cells via test data to examine progressively the flight feasibility. Since the lithium-sulfur battery with high energy density can facilitate the long endurance of UAS, its acquisition becomes very crucial. In order to maintain the performance of lithium-sulfur battery at low temperatures, the insulation devices are advised. Based on aerodynamic analysis, the configuration of aircraft was selected up to 15-meter wingspan and aspect ratio was kept 15. The total weight of the airplane assembly is about 100kg. Then, all computer-aided design (CAD) data of the aircraft structure is established by using the software (SolidWorks), which incorporates configuration, power, battery, solar panel, carbon composite structure, and etc. Finally, key technologies of each sub-system assessed the feasibility of high altitude long endurance (HALE) UAS which aims to provide further extended telemetry services in the future.

1. Introduction

The HALE was mainly developed as the low-cost telemetry platforms whose functions complement artificial satellites, such as real-time terrestrial surveys, meteorological observations, and telecommunications relays, etc. The advantages of solar-powered aircraft include rapid deployment time which is faster than satellite, and easier to operate and maintain. When the aircraft stays between the altitudes of 18-22km, it can be used as the function of communications satellite, and will have a very high commercial value and great application.

With increasing demand for high-capacity wireless services, HALE brings new challenges. The studies [1-3] proposed a cellular architecture for broadband communications through high-altitude platforms to augment network capacity, and they can deliver the same services to remote areas. Moreover, the high-altitude platform could be placed above ocean ship lanes, offering typical maritime services such as voice, data, video, paging and broadcasting. Up to date many countries and companies are racing to key technologies of solar-powered aircraft due to its potential applications.

The NASA Pathfinder-Plus carried commercial communications relay equipment successfully to transmit high definition television and wireless communication signals from 20km height. Since it has a good look down angle, the transmission utilized only one watt of power which is equivalent to 1/10,000 of power required by a terrestrial tower on the ground. Furthermore, the platform just like Pathfinder-Plus floating in the stratosphere can achieve much higher levels of frequency without the time delay [4].

In June 2016, Facebook's unmanned air vehicle, named Aquila, had completed the full-scaled maiden flight using solar-power. The Aquila carried a communications payload that used lasers to transfer data more than 10 times faster than existing systems [5]. The Facebook's engineers are working on new state-of-the-art data links for it.

However, the design challenges of HALE platform mainly involve the efficient power system, high-strength composite materials, efficient aerodynamic shapes, and cost effective fabrication. The preliminary work is to decide the basic configurations and utilize the design considerations of other solar-powered aircraft such as flying wing, propeller and high Lift/Drag ratio airfoil, etc. In this study, the numerical method was employed [6-8] to determine the weight and size of the solar-powered aircraft. This paper presents the design achievements and development status of the key technologies for solar-powered unmanned flight which currently remains aloft below 10 km height and stays than 8 hours duration.

2. The options of aircraft appearance and structural design

The high aspect ratio is typically one of key high-lift designs that are aiming to long endurance operating condition. Based on aerodynamic analysis, the appearance of aircraft selected an almost 15-meter wingspan with aspect ratio 15 in Fig. 1. According to this principle, the lift is equal to the weight of the aircraft. The lightweight design of aircraft is very crucial to reach our goals. In order to control the aircraft weight effectively, the optimal structural assembly is required through computer-aided design (CAD) model by using the software (SolidWorks). The entire solar-powered aircraft is shown in Fig. 2, which mainly contains airframe, propulsion, and subsystems. In the interest of minimizing aircraft weight, the wide use of carbon fiber to builds a very light and high stiffened structure. The total weight breakdown of the aircraft is 95.5 kg in Table 1.

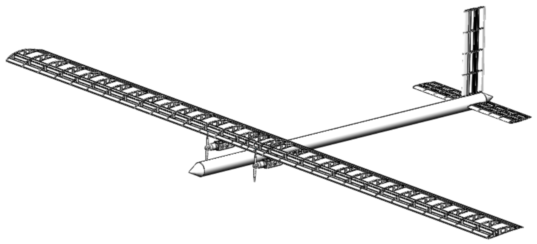


Fig. 1 Option of aircraft appearance

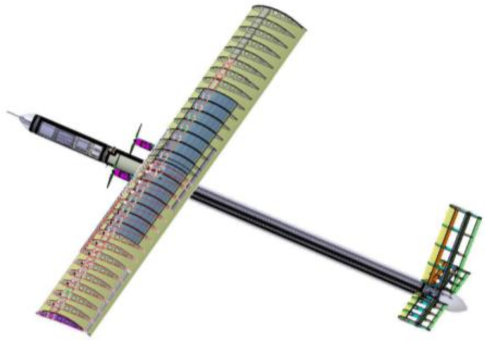


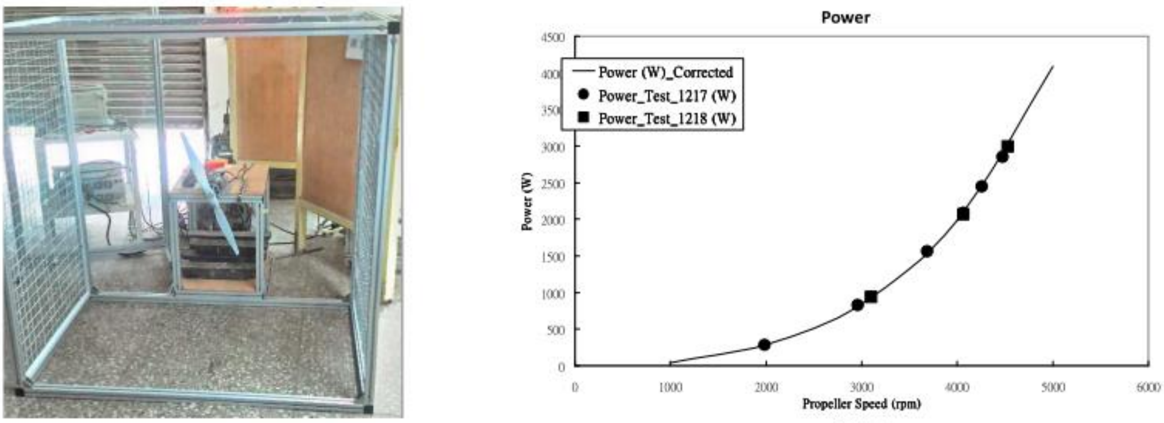
Fig. 2 Entire solar-powered aircraft

Table 1: Weight breakdown

Component	Target weight(Kg)	Current weight(Kg)	Delta weight(Kg)
Airframe	52.5	52.5	0
Propulsion (Motor, propeller, PMC)	9.0	8.4	-0.6
Subsystem(payload, FCS, battery)	38.5	34.6	-3.9
Gross Weight	100	95.5	-4.5

3. Power consumption profile

After determining the weight and size of the aircraft, the power consumption was calculated in order to assure there is enough power to monitor the health status during flight. The electric energy of aircraft was mainly provided by the lithium polymer battery and partly by the flexible thin-film solar cells. Since most of the electric energy is used on propulsion system, it was experienced through ground test in order to estimate precisely the total power consumption in Fig. 3. Consequently, the demand for capacity of lithium polymer battery is 4.4kWh and the flexible thin-film solar cell contributes 850Wh. The various stage of the power consumption is shown in Fig. 4, which contains standby, take-off, climb, cruise, descent and landing. Thus, the aircraft has sufficient power to achieve the aim with 10km height and 8 hours duration.



Thrust

Torque

Fig 3: ground test of motor

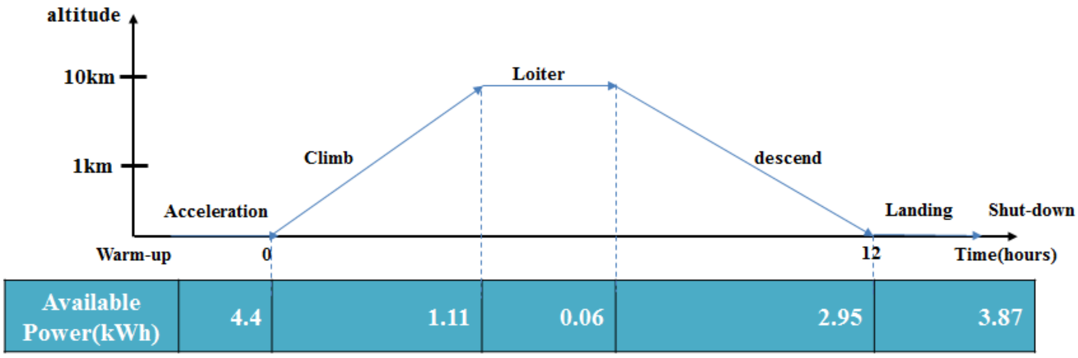


Fig 4: Power consumption profile

4. Flight envelope

The key design process of solar-powered aircraft is mainly based on weight and power balances. When the aircraft structur and power consumption were estimated, the optimal flight performance of solar-powered aircraft conducted by way of flight envelope. In this project, according to operating parameters and capabilities of three different motor speeds, the flight envelope of solar-powered aircraft is shown in Fig. 5. It shows the optimal flight performance at the motor speed of 4000 revolutions per minute (RPM) generates sufficient thrust to climb stably over 10km in height. The take-off climb speed is about 60 km / hr. Moreover, the design strength is shown in Fig. 5, which is higher than the flight performance to ensure the flight safety.

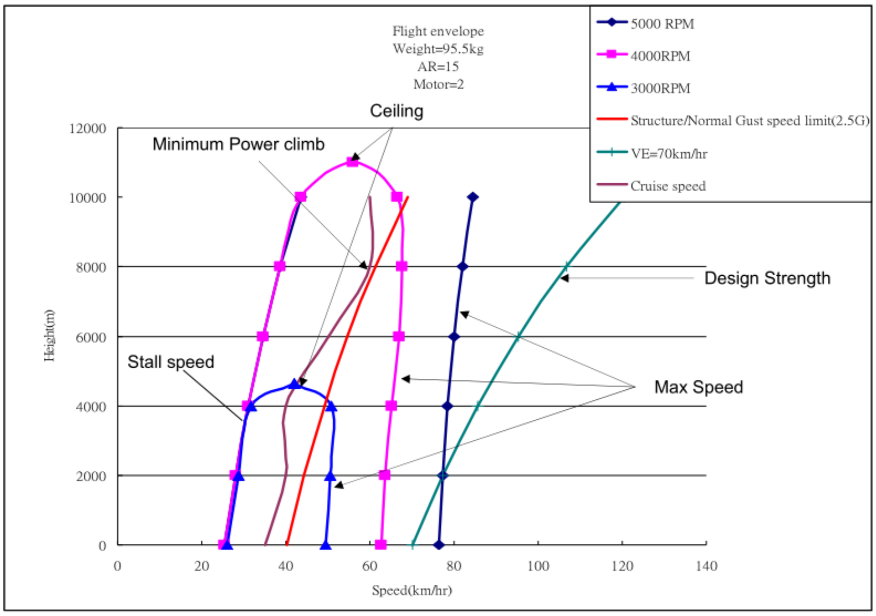


Fig. 5 Flight envelope

5. Development Status of the key technology

5.1 The efficiency of solar cells

The solar cell was placed on the upper surface of wing which continually charges the battery during the flight. The efficiency of the solar cell is very critical for long endurance of aircraft. For long-term planning, independent development of high efficient lightweight and flexible solar cells is necessary to fulfill sophisticated aircraft applications. The experimental thin-film solar cells are laid out in Fig. 6, which shows the five test arrays. Each array is composed of solar cells in 22- series and 2-parallel. The weight of each array is about 4.2g. All experiment data were measured using the outdoor sunlight. Currently, the test data show it’s capable of converting 27.45% of the Sun's rays into electricity in table 2. By contrast, ordinary solar cells are between 14% and 17% energy efficiency and much heavier than the thin-film counterparts.

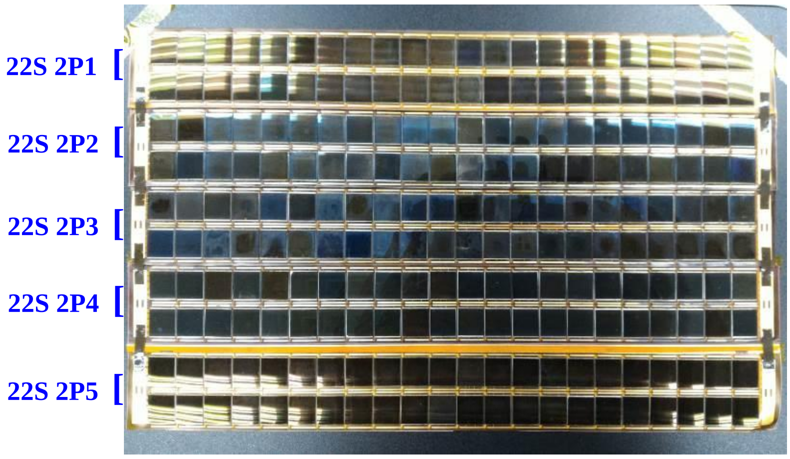


Fig. 6 Experimental thin-film solar cell

Table 2: Electrical property data

Test		日 照 (W/m2)	Pm(mw)	Vm (V)	Im (mA)	**Efficiency (%)**
22S 2P 1	1	721.60	976.59	47.46	20.58	29.29
	2	726.00	984.14	47.66	20.65	29.34
	3	733.70	993.27	47.46	20.93	29.30
Avg.		727.10	984.67	47.53	20.72	29.31
22S 2P 2	1	732.80	947.82	44.43	21.33	28.00
	2	730.30	941.12	44.62	21.09	27.89
	3	724.70	930.08	44.22	21.03	27.78
Avg.		729.27	939.67	44.42	21.15	27.89
22S 2P 3	1	747.80	899.41	45.03	19.97	26.03
	2	740.50	886.48	45.23	19.60	25.91
	3	740.80	876.80	44.63	19.65	25.62
Avg.		743.03	887.56	44.96	19.74	25.85
22S 2P 4	1	753.40	898.05	45.63	19.68	25.80
	2	749.20	894.38	45.43	19.69	25.84
	3	758.40	913.26	46.25	19.75	26.06
Avg.		753.67	901.90	45.77	19.70	25.90
22S 2P 5	1	757.20	990.84	45.65	21.71	28.32
	2	763.20	998.80	46.24	21.60	28.33
	3	762.40	993.52	46.05	21.58	28.21
Avg.		760.93	994.39	45.98	21.63	28.29
Total average						27.45

5.2 Lithium-sulfur battery environment test

The lithium-sulfur battery is of great interest for storing energy in the solar-powered aircraft, since its energy density is up to 400 ~ 600 Wh/kg about 2 or 3 times higher than other lithium batteries. Since low temperature at 10 km, it will deteriorate the lithium-sulfur battery performance. The battery efficiency at low temperature was estimated through environment test. The Fig. 7 shows the soft pack lithium-sulfur battery which was placed in the temperature cycle test cabinet with battery charge/discharge device outside. Every charge/discharge cycle of the battery was experienced in order to acquire the specific capacity of the battery at four temperatures: 20, 10, 0, and -10 degrees C in Fig. 8. Finally, the Fig. 9 shows charge/discharge curve of the lithium-sulfur battery, which illustrates battery capacity decayed much faster in the lower temperature domains. Besides, the soft pack lithium-sulfur battery still worked at the -10 ℃ without package, and the capacity of battery was reduced by 27% as compared with room temperature. In the future, with additional insulation device, the electrolyte performance will be improved to highly reduce losses.

Fig. 7 Soft pack lithium-sulfur battery and battery charge/discharge device

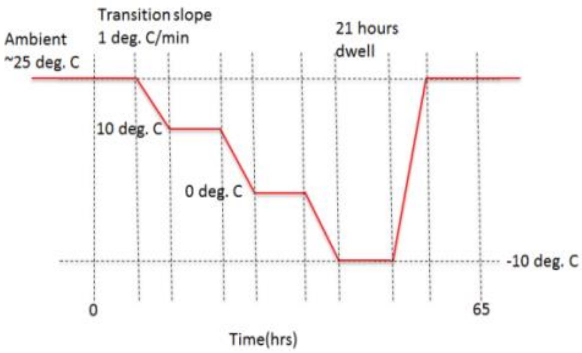


Fig. 8 Temperature record curve

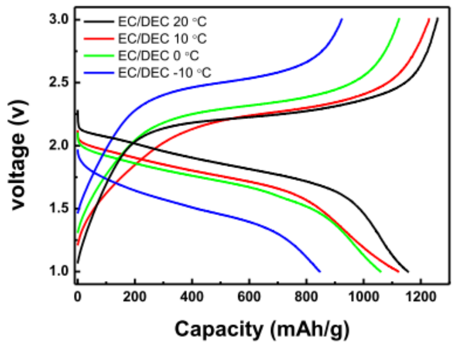


Fig. 9 Charge/discharge curve at different temperatures

6. Conclusion

The results of this preliminary study depict that the aircraft should make it possible to attain the aim which stays below 10 km with more than 8 hours duration. However, the design methodology was limited to a theoretical study, and only verified by simulations. It must be validated through the realization of flight experiments. The aircraft assembly will be implemented in the future. Meanwhile, the camera will be mounted on the aircraft to take the photographs. Gradually the other telemetry services will be applied on the aircraft.

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