High altitude long endurance of unmanned aerial vehicle (UAV) ITB solar panel conceptual design

M A Moelyadi1,*, M A Sulthoni2, M F Zulkarnain1, M F Akbar2, and B K Assakandari2
1 Flight Mechanics Research Group, Faculty of Mechanical and Aerospace Engineering, Bandung Institute of Technology, Jalan Ganesha No. 10 Bandung 40132, Indonesia
2 School of Electrical Engineering and Informatics, Bandung Institute of Technology, Jalan Ganesha No. 10 Bandung 40132, Indonesia

*Corresponding E-mail: moelyadi@ae.itb.ac.id

Abstract. One of the factors for the long endurance of high altitude long endurance (HALE) of an unmanned aerial vehicle (UAV) that belong to Institut Teknologi Bandung, Indonesia or called as HALE UAV ITB is the design of battery and solar panel. This paper discusses the method to calculate battery and solar panel requirements for HALE UAV ITB to fly for more than 24 hours at 20,000 feet. Several designs, configuration, and type of solar panels are analysed to fulfil HALE UAV ITB requirements. The variable compared is solar panel area, weight, and types. As a result, the use of Monocrystalline Silicon solar cell was found to be much more efficient than Polycrystalline Silicon, CIGS Thin Film, and Amorphous Silicon Thin Film with power generated per area of 224 Watt/m² and power per weight of 436 Watt/kg. The minimum area required for a Monocrystalline Silicon type solar cell to generate power is 5.94 m² with a total cell weight of 5.31 kg.

Keywords: unmanned aerial vehicle, high altitude long endurance, battery, solar panel

1. Introduction
Development of a High Altitude and Long Endurance (HALE) UAV may align to current issues such as regional border, disaster, and foreign areas. However, the development of a HALE UAV has its own obstacle, notably in obtaining high altitude flight and long flight duration. To obtain these capabilities, several aspects need to be considered: aerodynamic efficiency, motor-prop efficiency, battery and solar panel, lightweight airframes, efficient control, and optimum flight mission [1].

One of the most successful HALE UAV is Zephyr UAV [2] which set a record with Zephyr-s at 2018 flying for 26 days with recorded highest altitude at 74,000 feet [3]. Zephyr UAV uses carbon construction, flying at a very high altitude during the day while descending to a lower altitude during night to conserve energy. Other development including: Atlantik Solar, which record 3 days endurance flying at constant altitude of 2,000 feet [4]; Solar Impulse, manned HALE which has a record of 5
days of flight with the highest altitude of 28,000 feet [5]; and Korean Aerospace Research Institute with EAV-3 which has reached 18,000 km with using own design propeller at 2018 [6].

Institut Teknologi Bandung is currently developing a HALE UAV. It has MTOW of 50 kg and a wing loading of 2.1 kg/m². The aircraft has twin wing and triple boom configuration. Propulsion is provided by two electric motors. Battery is used as energy storage and the solar cell is used to charge the battery, to provide endurance of more than 24 hours. HALE ITB has a mission to climb and cruise at 20,000 feet, while at night descend to 5,000 feet to reserve energy. The HALE ITB UAV is shown in figure 1.

![Figure 1. Hale UAV ITB](image)

This study aims to discover the design, configuration, and type of solar panels which fulfil HALE UAV ITB requirements by comparing the solar panel area, weight, and types.

2. Materials and Methods

The method to calculate total solar panel and battery are shown in figure 2. It is an iterative method by calculating the required power and energy for given MTOW, performance, mission profile, and motor data. Power and energy required can then be used to calculate solar cell weight and area. The resulting weight and area are then checked so that the MTOW does not exceed initial guess, and solar panel area does not exceed available space on the wing. If the MTOW exceeds the initial guess, then the larger MTOW will be the new guess and then the iteration will restart.

Required power and energy will be calculated using the concept of total drag experienced equal to total thrust required. Total drag is obtained by assuming thrust to weight ratio for each phase of mission profile. It is assumed 0.03 for cruise and 0.22 for climb.

Total thrust is provided by the motor and propeller. Thrust provided are a function of airspeed, altitude, propeller efficiency, airspeed, and motor rpm. Motor requirements are obtained from its website [7]. However, as the specifications provided are only for static and sea level conditions, the motor-propeller is then replaced with NACA propeller with similar specifications from references [8], which has specifications for varying speed and rpm. It is found that T-motor 30” and 32” is similar to NACA Prop with 14 degree pitch. The corrected thrust from motor and propeller combination, at various airspeed, rpm, and altitude then can be obtained. This corrected thrust will then correspond to a certain throttle and electric power required.
The electric power required will be calculated for every phase in the mission profile. The mission profile is shown in figure 3. There are day cruise at 20,000 feet for 8 hours and night cruise at 5,000 feet for 10 hours. For climb, will only be calculated at sea level and for 2 hours. Electric power required times the duration of each phase will results in energy required. The total energy required for limited sunlight operation is used to calculate battery, while the total energy required is used to calculate solar cell.

In this section, some data are taken from several types of solar panels. solar panel data is obtained from measurements and datasheets. Some parameters to consider are the length, width, the weight of each cell, and efficiency. One additional parameter namely purchasing power is taken into account as cost - effective also an important factor in the production. These solar panels are obtained from several marketplaces.

| Name                        | Type                  | Width (mm) | Length (mm) | Cell Weight (g) | Efficiency (%) |
|-----------------------------|-----------------------|------------|-------------|-----------------|----------------|
| Sunpower Maxeon C60 Cell    | Monocrystalline Silicon | 125        | 125         | 8               | 22.4           |
| Xinpuguang PV Cell          | Monocrystalline Silicon | 125        | 125         | 8               | 19.6           |
| Sunyima Solar               | Monocrystalline Silicon | 125        | 125         | 5               | 17.28          |
| Xiamen Esunpower Solar      | Polycrystalline Silicon | 156        | 156         | 12              | 18.4           |
| Sunpower Flexible           | Monocrystalline Silicon | 540        | 1050        | 1750            | 17.6367        |
| SRFLEX04-N Solar            | Amorphous Silicon     | 665        | 1710        | 1700            | 14             |
From the analysis of mission profile and other factors, the power requirements for 24 hours flight obtained to be around 6984 Wh. This power requirement must be met by charging through solar panels. The amount of energy received at ground level from the Sun at its peak depends on the distance to the Sun and the time in, assuming that the value of the Earth-Sun distance is one astronomical unit, the direct sunlight on the Earth's surface when the Sun is at its peak will be around 1000 W/m².

Through analyzing data from the previous table and assuming that 60% of the sunlight from 12-hours(day) illumination will be effectively converted into electricity, this table will show the ability of each solar panel to receive power from the sun. 60% effective sunlight is assumed by using modified irradiance model from Reference [9].

**Table 2. Solar Panel Efficiency**

| Name                     | Efficiency (%) | Efficiency (W/m²) | 12-hours Efficiency (Wh/m²) |
|--------------------------|----------------|-------------------|-----------------------------|
| Sunpower Maxeon C60      | 22.4           | 224               | 1175.36                     |
| Xinpuguang PV            | 19.6           | 196               | 1028.44                     |
| Sunyima Solar Cell       | 17.28          | 172.8             | 906.7                       |
| Xiamen Esunpower Solar Cell | 18.4          | 184               | 965.47                      |
| Sunpower Flexible Solar Panel | 17.6367       | 176.367           | 925.42                      |
| SRFLEX04-N Solar Panel  | 14             | 140               | 734.6                       |
| SN-CIGS90W               | 17.2           | 172               | 902.51                      |

The battery sizing is done by stating some requirements needed for the battery. The propulsion subsystem uses two T-Motor MN1005 as the main thruster. This propulsion subsystem is planned to use 12S (around 48V) Lithium-Ion batteries as its power source. The first requirement is the battery capacity must fulfill total power needed when there is not enough sunlight. The second requirement is to have a combination of batteries that have voltage around 12S or 48V. This combination can be achieved by making twelve 1S batteries in series, six 2S batteries in series, four 3S batteries in series, three 4S batteries in series, two battery 6S in series, or one 12S battery. The 6S in series configurations are preferred because of simplicity of the wiring. The third requirement is the dimension of the battery.

The battery should be small enough to fit inside the main wing and rear wing. The fourth requirement is C rating. C rating of a battery is the maximum output current that the battery can wish to stand [10]. The battery combination must be capable of delivering up to 80A of current, which is the total maximum draw current from both motors. To meet the first requirement, the battery's capacity must be at least the same or more than total energy needed when there is not enough sunlight, which is 4200 Wh. Lithium-Ion batteries, with 243 Wh/kg, achieve the battery capacity at 17.2 kg.

**3. Results and Discussion**

**3.1. Battery**

The Navi Power 6S 7000mAh 2.5C Lithium-Ion battery is chosen as the battery to power the propulsion subsystem because it fulfills all the requirements. It weighs 640 grams and has power density 243 Wh/kg. Its size which is 144 x 42 x 62 mm makes the battery fit into both main wing and rear wing [11]. The number of batteries needed for perpetual flight is 26 batteries. The number of batteries is determined based on the total energy needs of the ITB HALE UAV to fly at night. During
the day, the solar panel subsystem operates the vehicle's motor & subsystems and charges the battery for the night time.

The total energy is obtained from the calculation between the mission profile and the capabilities of the existing motor. The power needed for HALE UAV ITB to climb is 922 W, for high altitude cruise, it takes 141 W of power, while low altitude cruise requires a power of 88 W. Total energy needed during daytime is 2781 W while at night is 4203 W. So that the total energy required for 24 hours of flying is 6984 W. That way, the battery capacity is 109% compared to the needs.

3.2. Solar Panel Sizing
The weight of the solar panel is an important parameter as the solar panels will be installed on the UAV. Based on the area of the wing that will be used, the number of cells needed to reach the entire wing area could be obtained. By conducting small-scale experiments with a series of solar panels composed of only a few cells and using laminated plastic as the panel’s cover and base, we can get the total laminate weight and the weight of lamination for each area per square meter.

![Figure 4. Small-scale experiments result using laminated plastic as solar cell’s cover and base](image)

**Table 3. Solar Panel Sizing**

| Name                      | Area(m²) | Cell per Panel | Total Cell Weight (kg) | Lamination Weight per Area (g/m²) | Total Lamination Weight (kg) | Total Panel Weight (kg) |
|---------------------------|----------|----------------|------------------------|-----------------------------------|-----------------------------|-------------------------|
| Sunpower Maxeon C60       | 5.94     | 381            | 3.05                   | 277.33                            | 2.26                        | 5.31                    |
| Xinpuguang PV             | 6.79     | 435            | 3.48                   | 258                               | 2.95                        | 6.43                    |
| Sunyima Solar Cell        | 7.70     | 493            | 2.465                  | 154.8                             | 3.8                         | 6.26                    |
| Xiamen Esunpower Solar Cell | 7.23     | 298            | 3.576                  | 771.36                            | 3.16                        | 5.73                    |
| Sunpower Flexible Solar Panel | 7.55   | 14             | 24.5                   | -                                 | -                           | 24.5                    |
| SRFLEX04-N Solar Panel    | 9.51     | 9              | 15.3                   | -                                 | -                           | 15.3                    |
| SN-CIGS90W                | 7.74     | 15             | 15                     | -                                 | -                           | 15                      |
From the table, it is shown that the Sunpower Maxeon C60 solar cell has the greatest efficiency (22.4%) compared to other types of solar cells / solar panels followed by Xinpuguang PV (19.6%). Sunpower Maxeon C60 also has the lowest total weight. Xiamen Esunpower Solar Cell has the lowest cell needed per panel with 298 cells followed by Sunpower Maxeon with 381 cells per panel. Xiamen Esunpower also has lowest lamination weight per area making it possibly the lightest solar cell. Sunpower Maxeon C60 has the lowest area needed with the highest power efficiency. All types of solar cells / solar panels need less area than HALE UAV ITB wing total area

3.3. Weight Sizing
By calculating structural weight, battery weight, and solar panel weight, we can determine which solar panel that meets the HALE UAV ITB MTOW (50 kg). By subtracting structural weight, which is predicted to be 22.5 kg, subsystems weight, which is 3 kg, and battery weight, which is 17.3 kg, the maximum weight for solar panels can be obtained. This maximum weight for the solar panels is 7.2 kg. This means Sunpower Maxeon C60, Xinpuguang PV, Sunyima Solar Cell, and Xiamen Esunpower Solar Cell achieved the weight requirements. The best solar cell that has the lowest total panel weight which is 5.31 kg and lowest area which is 5.94 m² is the Sunpower Maxeon C60. These solar cells have low lamination weight by using laminated plastic.

4. Conclusion
In conclusion, there are four solar panels that meet HALE UAV ITB requirements based on our data. These are Sunpower Maxeon C60, Xinpuguang PV, Sunyima Solar Cell, and Xiamen Esunpower Solar Cell. All of these are monocrystalline and polycrystalline solar cells. These solar cells need an area less than the total wing area of HALE UAV ITB and weigh below maximum weight for solar panel requirement. This is due to high efficiency and low lamination weight by using laminated plastic in covering those solar cells. Sunpower Maxeon C60, which is monocrystalline solar cells achieve the lowest area with 5.94 m² and lowest total weight with 5.31 kg.

References
[1] Moelyadi, M. A., Rosid, N. H., Hakim, M. L., Rumansyah, K. K., Manurung, F. N., & Darmansya, R. 2018 Preliminary Design and Analysis of Hybrid Solar Powered High Altitude Long Endurance UAV. International Conference on Intelligent Unmanned Systems.
[2] Jane's 2017. High-flying bird: Zephyr remains in the vanguard of solar-powered flight.
[3] Thisdell, D. 2018. Airbus sets flight endurance record with Zephyr UAV. Retrieved 8 26, 2020, from www.flightglobal.com/airbus-sets-flight-endurance-record-with-zephyr-uav/129186.article
[4] Oettershagen, P. et al 2015. A solar-powered hand-launchable UAV for low-altitude multi-day continuous flight. IEEE International Conference on Robotics and Automation.
[5] Solar Impulse Foundation Our Adventure. Our Adventure.aroundtheworld. solarimpulse.com/adventure.
[6] Park, D., et al 2018. Design and Performance Evaluation of Propeller for Solar-Powered High-Altitude Long-Endurance Unmanned Aerial Vehicle. International Journal of Aerospace Engineering.
[7] T-Motor. T-Motor Store. store-en.tmotor.com
[8] McCormick, B. W. (1979). The analysis of propellers including interaction effects. NASA.
[9] Duffie, J. A. (2013). Solar Engineering of Thermal Processes. John Wiley & Sons.
[10] Huai Chuangfeng, Liu Pingan,, Jia Xueyan, “Measurement and analysis for lithium battery of high-rate discharge performance,” Procedia Engineering 15 (2011) 2619 – 2623.
[11] Navi Power battery store, navi-power.com/product/navi-power-7000mah-22-2v-2-5-6c-6s2p
[12] Sunpower C60 Product Datasheet, www.taipo-tech.com/wp-content/uploads/2017/06/Sunpower-solar-cell.pdf
[13] Xinpuguang product store, www.aliexpress.com/item/32957112785.html
[14] Sunyima product store, www.aliexpress.com/item/4000277722639.html
[15] Xiamen product store, www.aliexpress.com/item/32626393408.html
[16] Sunpower flexible panel store, www.enfsolar.com/pv/panel-datasheet/crystalline/33938
[17] SRFLEX04-N solar panel product store www.alibaba.com/product-detail/90w-250w-275W-High-Quality-rollable_60634545182.html
[18] SN-CIGS90W product store www.alibaba.com/product-detail/CIGS-Rollable-Solar-Panel-Semi-Flexible_62435314206.html