Advances in Aircraft and Spacecraft Science, *Vol. 11, No. 1 (2024) 23-31*
https://doi.org/10.12989/aas.2024.11.1.023

A prototype to improve endurance of solar powered aircraft using MPPT and rechargeable battery

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(Received December 28, 2023, Revised April 24, 2024, Accepted April 26, 2024)

Abstract. This paper addresses the enhancement of long-endurance solar-powered aircraft through the integration of a rechargeable battery and Maximum Power Point Tracking (MPPT) controller. Traditional long-endurance aircraft often rely on non-renewable energy sources such as batteries or jet fuel, contributing to carbon emissions. The proposed system aims to mitigate these environmental impacts by harnessing solar energy and efficiently managing its storage and utilization. The MPPT controller optimizes the power output of photovoltaic cells, enabling simultaneous charging and discharging of the battery for propulsion and servo control. A prototype is presented to illustrate the practical implementation and functionality of the proposed design, marking a promising step towards more sustainable and enduring solar-powered flight.

Keywords: long endurance; MPPT; renewable energy; solar panel; solar powered aircraft

1. Introduction

During the 1970s fuel crisis, the utilization of solar energy through photovoltaic (PV) cells emerged as a viable alternative energy source. PV panels, capable of converting solar energy into electricity, gained prominence due to their potential to mitigate the impact of the fuel shortage (Lotfabadi 2015, Kousoulidou and Lonza 2016). Being an environmentally friendly energy source, characterized by significantly reduced carbon emissions, solar energy gradually infiltrated the aviation sector (Gonzalez-Garay *et al.* 2022, Yusaf *et al.* 2023).

Solar-powered aircraft have surpassed traditional counterparts due to their inherent capacity to self-generate energy for propulsion and control surfaces, eliminating the dependence on fuel for operation (Khoshnoud *et al.* 2020, Gierulski *et al.* 2021). Their prolonged flight endurance without refueling renders them particularly advantageous, enabling applications such as surveillance and providing internet services to remote areas (Zhu *et al.* 2014, Baharozu *et al.* 2017). In contrast, conventional long-endurance aircraft rely on fuel, necessitating periodic landings for refueling. The utilization of photovoltaic cells to power these extended-flight aircraft presents an efficient solution, avoiding carbon emissions associated with fuel combustion (Gao *et al.* 2013, Hassanalian *et al.* 2014).

Despite solar power's limitation to daylight hours, the integration of rechargeable batteries

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http://www.techno-press.org/?journal=aas&subpage=7 ISSN: 2287-528X (Print), 2287-5271 (Online)

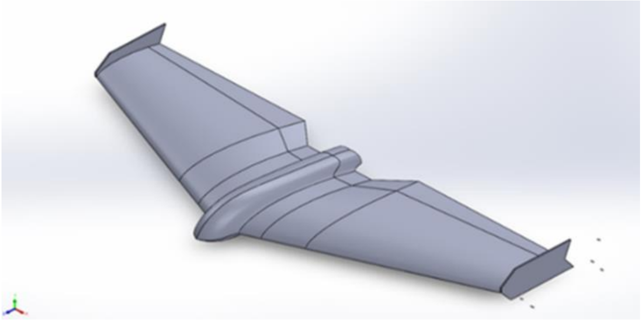

Fig. 1 Final prototype design using solid works

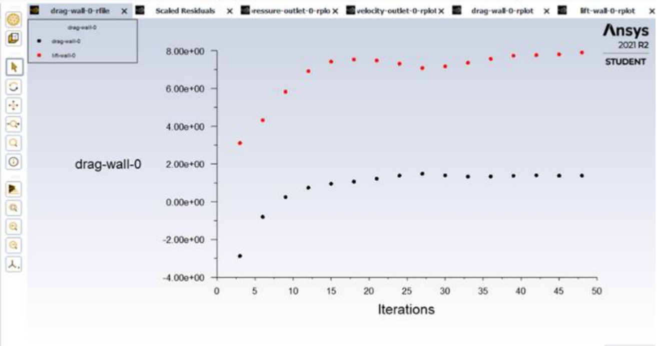

Fig. 2 Lift and drag parameters using ANSYS (50 iterations)

addresses this challenge by ensuring continuous aircraft operation during low-light or nighttime conditions. Employing brushless motors enhances efficiency by minimizing friction within the propulsion system (Choi *et al.* 2020). Implementing Maximum Power Point Tracking (MPPT) controllers optimizes solar cell output, thereby augmenting aircraft endurance (Sener *et al.* 2020, Binkowski 2020). This strategy involves charging the battery while simultaneously discharging power to fuel servos and brushless motors (Ram *et al.* 2017, Murdoch *et al.* 2013, Safyanu *et al.* 2019).

This study aims to propose a design enhancing the endurance of solar-powered aircraft by incorporating MPPT technology and rechargeable batteries.

2. Prototype design and set up

Prior to implementing the electrical system for solar power, the prototype structure undergoes design modeling through SolidWorks software, while the aerodynamic impact of fluid flow over the aircraft body is evaluated using ANSYS. To accommodate 15 solar panels on each wing, the aircraft wing design incorporates a larger surface area. The finalized prototype design, created with SolidWorks, is illustrated in Fig. 1. Subsequent testing via ANSYS, simulating air as the fluid medium, confirms the prototype's ability to generate lift, validating its potential for practical flight. Analysis of the lift coefficient (red) to drag coefficient (black) ratio, depicted in Fig. 2, yields a calculated value of 6.1.

Table 1 Comparison between monocrystalline and polycrystalline PV cells

Parameters	Monocrystalline	Polycrystalline
Cost	High	Low
Efficiency	High, 15%-20%	Low, 13%-16%
Appearance	Dark blue colour	Light bluish colour
Lifespan	25 years minimum	25 years maximum

Fig. 3 Monocrystalline PV cell used for prototype design

2.1 Propulsion motor and servos

The flying wing aircraft represents a departure from standard aircraft designs, notably lacking a traditional rudder and instead employing elevons that serve dual functions as elevators and ailerons. In this prototype, 9-gram micro servos are utilized for the elevon surfaces, with two servos allocated per surface due to their slight lightweight capacity. Given the lightweight nature of the elevons, minimal stress is anticipated on the servos.

Furthermore, a 100-gram motor is employed in a reverse configuration at the rear end of the fuselage to provide the necessary thrust for the flying wing. The motor, powered by a 14.8 V, 3400 mAh rechargeable battery, exerts a maximum pull of just above 3 A when the throttle is engaged at full power, achieving a speed of 5328 rpm with the propeller. The brushless nature of the motor minimizes current consumption owing to the absence of friction.

Micro-controller-operated servos effectively manipulate the control surfaces, specifically the elevons, combining aileron and elevator functionalities. The servos demonstrate efficient control over these surfaces, operating seamlessly in deflecting and managing the aircraft's movements.

2.2 Selection of Photovoltaic (PV) cells

PV cells come in two main types: polycrystalline and monocrystalline. Monocrystalline cells use a single silicon source, while polycrystalline cells are made from a mix of silicon sources. Due to this variation, polycrystalline cells are less efficient than monocrystalline ones, as outlined in Table 1. Despite potentially higher costs, monocrystalline cells are favored for this prototype due to their superior efficiency and longer lifespan, and the image of PV cell is shown in Fig. 3.

Key specifications for the chosen monocrystalline PV cell:

Table 2 Comparison between Li-ion and LiPo battery types

Criteria	Lithium-ion	Lithium-ion Polymer
Weight	Slightly heavier	Light weight
Price	cheap	Expensive
Conversion rate of charge to power	85-95%	75-90%
Aging	Suffer from aging over time.	Shorter lifespan

Max power: 2.8 W per cell
Max voltage output: 0.5 V
Max current: 5.24 A
Efficiency: 17.64%
Thickness: 160 μm
Dimensions: 125 mm by 125 mm

2.3 Selection of rechargeable battery

Rechargeable batteries, capable of multiple charge-discharge cycles, offer an extended lifespan compared to disposable ones. They rely on electrochemical cells and come in various types like lead-acid, nickel-cadmium (NiCad), lithium-ion (Li-ion), lithium-ion polymer, and nickel-metal hydride (NiMH). While pricier, these batteries endure numerous recharge cycles, far surpassing disposable options. For instance, certain lithium-ion batteries retain 80% performance even after 500 charges, making them a cost-efficient choice over repeated disposable battery purchases.

Two specific types, lithium-ion and lithium-ion polymer, differ in their composition and characteristics:

- Lithium-ion: Comprising positive and negative electrodes separated by a liquid chemical, these batteries boast high energy density and lack memory effect. Though cost-effective, they risk explosion at high temperatures, albeit highly unlikely.
- Lithium-ion polymer: These compact batteries utilize solid or gel-like electrolytes, enhancing safety by minimizing leakage risks. However, they're costlier, prone to quicker charge loss, and lack the endurance needed for prolonged solar-powered aircraft flights.

The consolidated comparison between Li-ion and LiPo battery types is shown in Table 2. Despite their respective strengths and weaknesses, the lithium-ion battery stands out for higher power output and cost-efficiency, aligning well with the needs of the current prototype.

The specifications for the selected battery and MPPT controller:

- Battery:

Capacity: 3350 mAh
Voltage: 3.7 V
Charging voltage: 4.2 V
Storage temperature: Max 50°C

- MPPT Controller:

Max charging current: 5 A
Max output voltage: 26 V
Max input voltage: 28 V

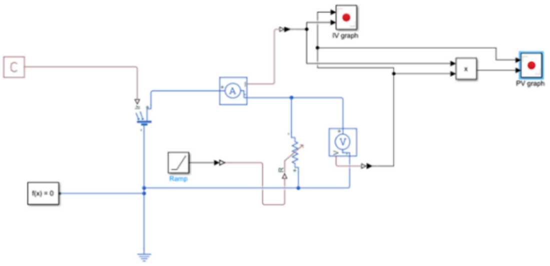

Fig. 4 Simulink set up to plot electrical characteristics of PV cell used for prototype design

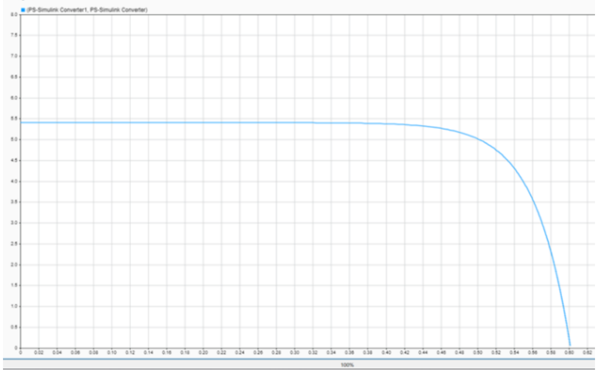

Fig. 5 IV characteristic of PV cell

The MPPT controller optimizes power output by tracking maximum voltage and current values. In this prototype, the controller identifies a maximum power of 249.6 W at 7.8 A and 32 V, aiming to sustain this optimal power level.

3. I-V Characteristics of solar cells using simulink

Before proceeding with practical tests, a simulation study was conducted using Simulink to analyze the IV (current vs. voltage) characteristics of the PV cell, as illustrated in Fig. 4. This simulation is crucial for determining the maximum power output achievable from the cells. The IV and power vs. voltage results displayed in the graph plotter (Figs. 5 and 6) align with expectations, confirming the anticipated maximum power of around 2.8 W per cell. The graph plotter indicates a maximum power close to 2.56 W, a value consistent with the specifications provided for the purchased PV cells. The estimated current of 5.24 A, as per the PV cell specifications, is also validated by the graph plotter in Fig. 5, which shows a current at maximum power (I_{mp}) value of approximately 5 A. Consequently, the simulation yields values closely resembling the specified characteristics of the PV cells.

4. Prototype set up and discussion

Body-the final prototype assembly involved integrating all electronics with the body structure,

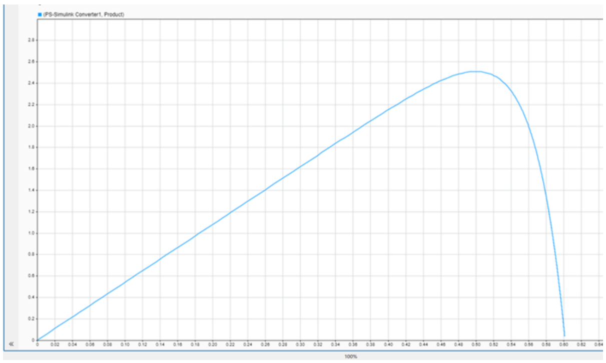

Fig. 6 PV characteristic of PV cell

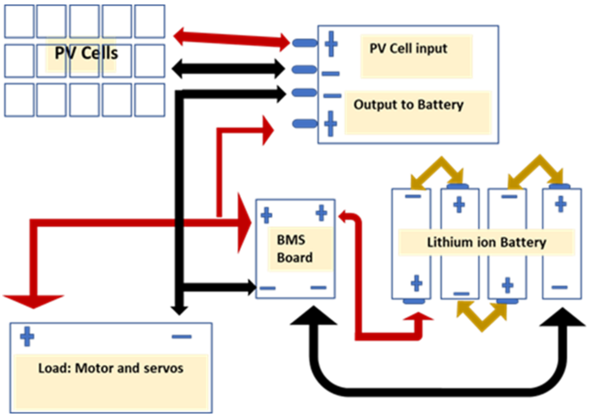

Fig. 7 Block diagram for electrical component connection

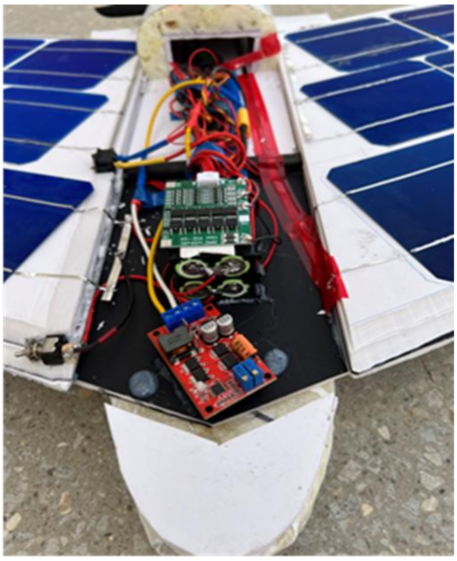

Fig. 8 Complete circuit connection showing all the components that make up the circuit. (Switches were made for the battery and MPPT controller to easily turn it on or off depending on whether it is being used or not)

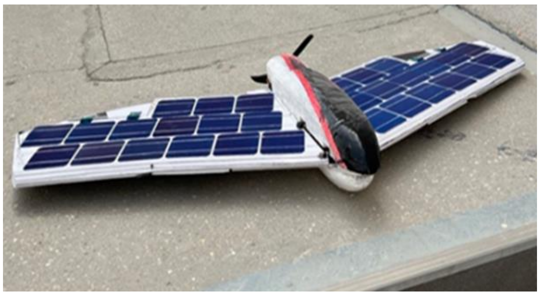

Fig. 9 Final prototype

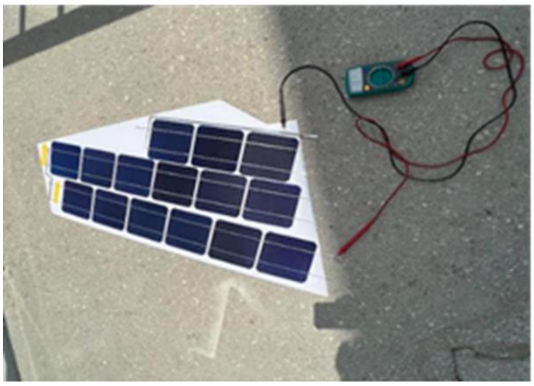

Fig. 10 Testing of PV cells output from one wing which are connected one in series

a challenging process given the requirement of a 1.76-meter wingspan. The initial stages involved crafting both wings using a 1:1 scale blueprint and later incorporating elevon cut-outs for the installation of elevon surfaces. The fuselage was constructed using expanding PU foam spray. Subsequently, the electrical system was installed, guided by the block diagram displayed in Fig. 7, which illustrated the connection of various components.

The circuit design aimed to link the PV cells to the MPPT input and transfer the output voltage from MPPT to the battery management system (BMS) board. This setup included a parallel load connection to power the motor and servos, as depicted in Fig. 8. The prototype's final appearance is showcased in Fig. 9, featuring 15 PV cells per wing.

Upon connecting the PV cells in series, testing was conducted during peak sunlight to ascertain the maximum voltage output, measured at 8.15 V from one wing, as illustrated in Fig. 10. Concurrently, the current was measured at 4.8 A. Calculating the power from one wing resulted in P=8.15 V×4.8 A=39.12 W. Thus, the combined output power from 30 PV cells equated to 78.24 W.

The power output from one PV cell was found to be 2.6 watts. This is a value that is close to the simulated value which was around 2.56 watts. Efficiency is another parameter that is important for PV cells. From Fig. 6, values of ‘V_{mp}’ (Voltage at maximum power), and ‘I_{mp}’ (current at maximum power), and hence, the efficiency of PV cells can be found.

Efficiency is given as Eq. (1)

$$\eta = \frac{P_{\max}}{P_{in}} = \frac{V_{mp} \times I_{mp}}{P_{in}} \times 100 \tag{1}$$

Pin is the irradiance for 1 PV cell which is 1040 W/m^2. But this is square metre, and it is needed for one PV cell which is 12.5 by 12.5 centimetres. Radiance was then calculated to be 16.25 W/m^2.

Efficiency is therefore Eq. (2)

$$\eta = \frac{0.6 \times 5.42}{16.25} \times 100 \tag{2}$$

The practical test and simulation together produced values that are similar to one another proving that the solar cells operate as required.

The research showed that the solar cells used in the prototype worked well. Both the actual tests and computer simulations gave similar results, proving the accuracy of our data. The power produced by a single solar cell closely matched what we predicted using the computer. We found that these solar cells are about 20% efficient in turning sunlight into electricity. Overall, these findings confirm that the solar cells are effective and reliable for generating power in our prototype.

5. Conclusions

The research shows a major advancement in the progress of solar-powered aircraft with long endurance by combining MPPT controllers and rechargeable battery technology. The ANSYS design simulations enhanced the aircraft's structure and aerodynamic performance leading to a lift-to-drag ratio of 6.1, demonstrating the successful incorporation of solar power into the aircraft design. This guarantees steadiness and continuous flying while carrying out extended missions powered by solar energy. Simulink simulations gave important information on the solar-powered aircraft's performance and efficiency by examining the IV and power vs. voltage characteristics of the PV cells, resulting in an anticipated power output of approximately 2.8 W per cell. The close match between simulation and actual outcomes boosts trust in the prototype's design and confirms the choice of key components like PV cells and MPPT controllers.

Although the MPPT has shown to effectively recharge the battery and utilizes 30 PV cells to produce a current of 5 A at 16 V, there is still potential for enhancement. Potential improvements may include integrating Fresnel lenses or other specialized magnifying lenses to focus sunlight onto PV cell surfaces, potentially increasing the output voltage and enhancing the performance and efficiency of the aircraft's power system. Ultimately, the ongoing pursuit of innovative technologies promises to further elevate the potential and capabilities of solar-powered flight, paving the way for more sustainable and enduring aerial operations. Combining advanced power management systems with utilizing solar energy effectively can lead to more environmentally friendly and efficient long-endurance flights.

Acknowledgments

The authors would like to express their gratitude towards Faculty of Engineering, Emirates Aviation University, Dubai for providing the necessary infrastructure to carry out this work successfully.

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