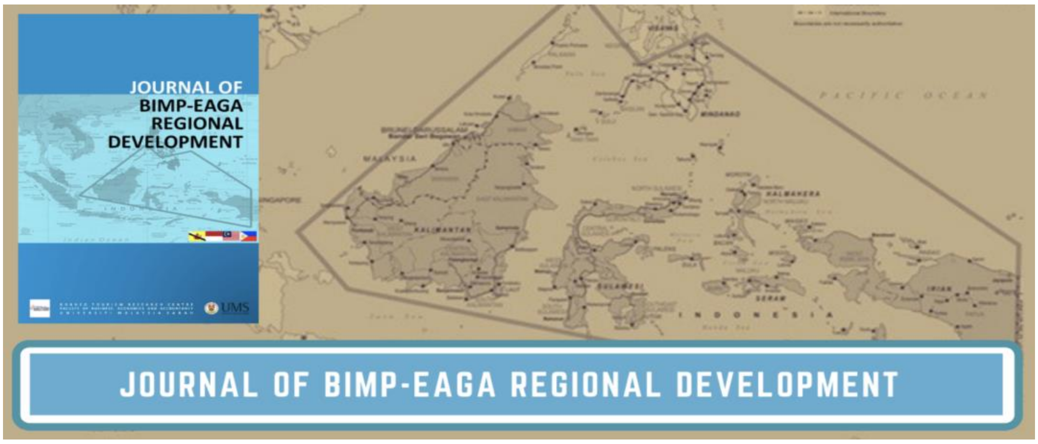


# Design and Fabrication of a 3D-printed Drone with an Integrated Solar Charging System for Enhance Aerial Surveillance and Sustainability

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**Abstract**

This study presents the design and fabrication of a 3D-printed drone with an integrated solar charging system to enhance aerial surveillance capabilities while promoting sustainability. The drone's lightweight yet durable structure was developed using advanced 3D printing technology with ABS+ filament, and its design was optimized through simulations in SolidWorks to ensure structural integrity and aerodynamic efficiency. A solar charging system was integrated to achieve extended flight durations, featuring flexible solar panels and a Maximum Power Point Tracker (MPPT) for efficient energy conversion. Key components, including a Speedy Bee F405 flight controller, brushless DC motors, and a high-resolution surveillance camera, were strategically incorporated to support surveillance operations. Performance tests demonstrated the drone's capability for prolonged and efficient flight, validating the effectiveness of solar-assisted power. This research highlights a cost-effective, eco-friendly solution for environmental monitoring, disaster response, and security surveillance applications, emphasizing the synergy between advanced materials, innovative design, and renewable energy technologies.

*Keywords: 3D-printed Drone, Aerial Surveillance, Solar Charging System, Sustainability, Structural Integrity, and Renewable Energy*

## 1. Introduction

This study focuses on the design, fabrication, and performance evaluation of a 3D-printed drone equipped with a solar charging system. The primary goal is to extend flight duration by integrating flexible solar panels into the drone's structure while ensuring stable flight, structural integrity, and surveillance capabilities. The drone's design will be customized using SolidWorks 2020 for 3D modeling and manufactured with a Creality K1 Max 3D printer. The selected material, ABS+ filament from eSun, provides durability and strength suitable for UAV applications. The drone's power system consists of a battery, an MPPT controller, and a Speedy Bee F405 flight controller, all integrated into the 3D-printed frame. Flexible solar panels are mounted on the drone's upper surface to maximize solar energy collection, taking advantage of their adaptability to curved structures. The propulsion

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system includes four motors and rotors attached to each arm, simulating a quadcopter flight mechanism. A high-resolution camera is incorporated for surveillance applications, enabling real-time monitoring of hard-to-reach areas.

The research explores the factors influencing the performance and design of a solar-powered, 3D-printed drone. It focuses on material selection, design, weight, and balance, analyzing their effects on the drone's overall performance and condition. Additionally, the study aims to identify observable signs of failure in the drone's structure or function. Another key aspect is evaluating the drone's performance at high altitudes to assess its stability and battery efficiency. Most conventional drones require multiple batteries for extended flight durations, necessitating battery replacements and recharging between flights. To address this limitation, the researchers aim to integrate a solar charging system into the drone's body, leveraging the customizability of 3D-printed structures to accommodate solar panels efficiently.

The primary objective of this study is to design and construct a drone structure for surveillance purposes using 3D printing technology. To achieve this, the study focuses on several specific goals. First, the drone model and structure will be designed using 3D CAD software to optimize performance and functionality. Next, stress, strain, deformation, gravity, vibration, and aerodynamic simulations will be conducted to validate the design's structural integrity. The study also involves fabricating the drone structure through 3D printing techniques to develop a fully functional model suitable for real-world applications. Additionally, the system's wiring and assembly layout will be designed to ensure seamless integration into the drone's structure. Lastly, a charging system will be developed by implementing solar charging technology to enhance the drone's operational efficiency.

## 2. Literature Review

Developing a sustainable and reliable 3D-printed, solar-powered drone represents a notable advancement in unmanned aerial vehicles (UAVs) driven by innovation and technological progress. Designing such a system requires meticulous attention to several key aspects, including the drone's structural integrity, weight, and performance. The frame must be optimized to accommodate electrical components, ensure aerodynamic stability, and maintain rigidity without compromising weight (Coe et al., 2019). The selection of materials is critical for reliability, with Polylactic Acid (PLA) being a promising candidate due to its balance of strength, weight, and ease of printing in Fused Deposition Modeling (FDM) applications (Yap et al., 2023). Other materials, such as carbon fiber composites, are also increasingly being explored for enhanced strength-to-weight ratios (Jung et al., 2021). The drone's design encompasses various factors, from the internal structure to optimize strength and stability to the selection and configuration of propeller blades, which impact the weight and drag experienced during flight. Optimizing these variables is essential to ensure efficient lift and power consumption (Unmanned Systems Technology, 2022). The number of propeller blades and shape can influence the drone's maneuverability and energy efficiency, which is particularly important for drones with solar power (Stojanovic et al., 2020).

Moreover, the application of 3D-printed solar-powered drones extends across diverse sectors such as agriculture, surveillance, emergency response, and scientific research, providing a sustainable power source and customizable designs suited to specific operational needs (Rahman et al., 2021). Drones are expected to offer enhanced efficiency, durability, and reliability in these applications. The strategic placement of solar panels is a key factor to consider, as it affects the drone's overall weight distribution and aerodynamic performance (Bari et al., 2022). Using lightweight materials for the drone body and ensuring optimal placement of the solar panels help mitigate adverse effects on flight dynamics and the drone's structural integrity.

Considering all the factors for creating the drone, the study of Zhang et al. (2021) shows that the design layout of the integrated battery plays a significant role in optimizing the performance of a solar-powered drone. As batteries are part of a weight load in the structure, simulating different layouts shows different results in optimizing the carrying path of the drone. Considering the deformation of the structure, a non-linear geometry design can best suit the layout. With various design layouts, mechanical performance significantly increases. As the drone is solar-powered, batteries still play a significant role, especially since solar can charge it for night operation. Different layout designs are presented to be the best usage in optimized operation for the drone, such as free optimization that results in high performance but low in manufacturability, a pure periodic design that has minimal improvements but is convenient in manufacturing, and the segmentally periodic optimization provides the best results in balancing the performance and the convenience in manufacture. These results show how balancing the drone's weight can improve and optimize the drone's air operation.

## 3. Methodology

This research aims to develop a 3D-printed, solar-powered drone optimized for surveillance applications through a systematic approach involving design, material selection, fabrication, and testing. The design process begins with the use of SolidWorks 2020, where the drone's structural components are modeled to ensure compatibility with electrical parts such as the motors, battery, and flight controller. Emphasis is placed on optimizing aerodynamics, weight distribution, and stability, mainly focusing on the placement of the solar panels to maximize energy capture without compromising flight performance. To verify the drone's structural integrity and performance, simulations are conducted in SolidWorks to evaluate stress, strain, deformation, and aerodynamic efficiency under various conditions, including high altitudes and extreme temperatures.

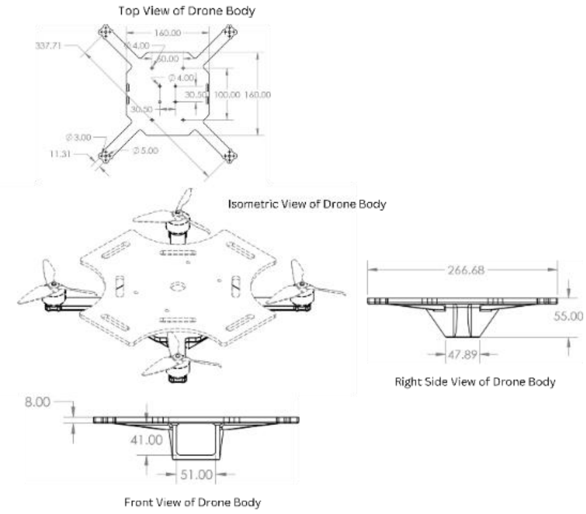


Figure 1: Drone 3D Model Design
(Industrial Design Patent Registration No.: 3/2024/050711)

For material selection, ABS+ (Acrylonitrile Butadiene Styrene) filament is chosen for its durability, heat resistance, and strength. However, alternative materials like Polylactic Acid (PLA) and carbon fiber composites may also be tested for comparison. The drone is fabricated using the 3D printer, and various print settings, including layer height, print speed, and infill density, are experimented with to ensure the final structure is both lightweight and durable. Following the printing process, the drone is assembled with electrical components, including the Speedy Bee F405 flight controller, electric motors with rotors, and a solar panel system strategically placed to minimize impact on the drone’s weight and aerodynamics.

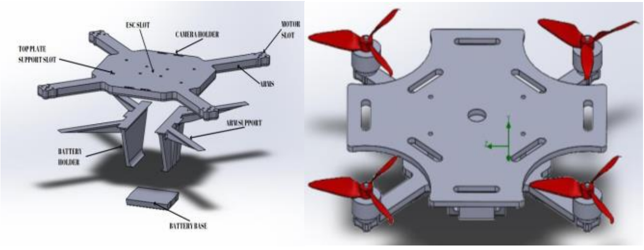

Figure 2: Rendered 3D Model Drone

Once the drone is fully assembled, it undergoes performance testing, including flight tests, to assess stability, maneuverability, and energy efficiency from the solar panels. Weight and balance tests are conducted to ensure the proper center of gravity, while structural integrity is evaluated through drop and vibration tests. Thermal tests are also performed to assess the drone's performance under high-temperature conditions. High-altitude flights are carried out to evaluate the drone’s behaviours in thin air, focusing on stability and solar power generation. Data from these tests are collected and analyzed to measure flight duration, battery consumption, and motor temperatures, as well as to assess the overall performance of the solar power system. The analysis of this data allows for the identification of any design flaws or areas for improvement. Based on these findings, recommendations are made for optimizing the drone’s design, materials, and performance, ensuring it is better suited for future surveillance applications.

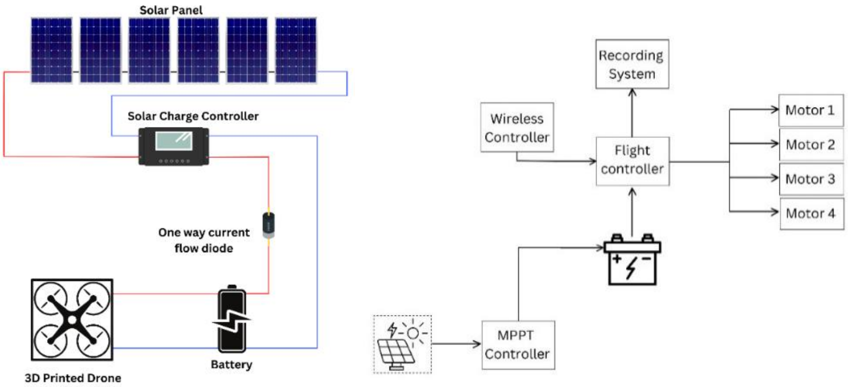


Figure 3: Actual Diagram of the Solar Charging System

In Figure 3, a solar-powered drone's energy system is designed to efficiently harvest, regulate, and distribute power while incorporating safety and control mechanisms. Flexible solar panels capture solar energy, which is directed to a Maximum Power Point Tracking (MPPT) controller that optimizes power extraction by adjusting voltage and current for peak efficiency. The MPPT controller regulates the output to 36V with a current of 120mA in a series configuration. A diode is integrated to ensure unidirectional power flow, preventing reverse currents that could damage the solar panels or reduce charging efficiency. The regulated energy is then stored in the onboard battery, which powers the propulsion system, flight controller, and auxiliary electronics.

The flight controller, Speedy Bee F405, manages real-time flight dynamics and stability, while a wireless controller allows remote operation of movements and functions. The recording system is integrated into the control mechanism, enabling users to start and stop video recording via the wireless interface. The flight controller software implements A critical safety feature to prevent uncontrolled crashes due to low battery voltage. When a predefined low-voltage threshold is detected, the drone autonomously initiates a gradual descent without manual intervention. Shock-absorbing paddings are incorporated into the landing gear to reduce impact forces and protect the structural integrity of the 3D-printed frame.

Integrating solar power into the drone's energy system extends flight duration and enhances operational sustainability. The combination of MPPT-based power regulation, controlled energy distribution, and fail-safe landing mechanisms ensures efficient performance while maintaining safety and reliability in real-world applications.

## 4. Findings

### *4.1. Design Simulation*

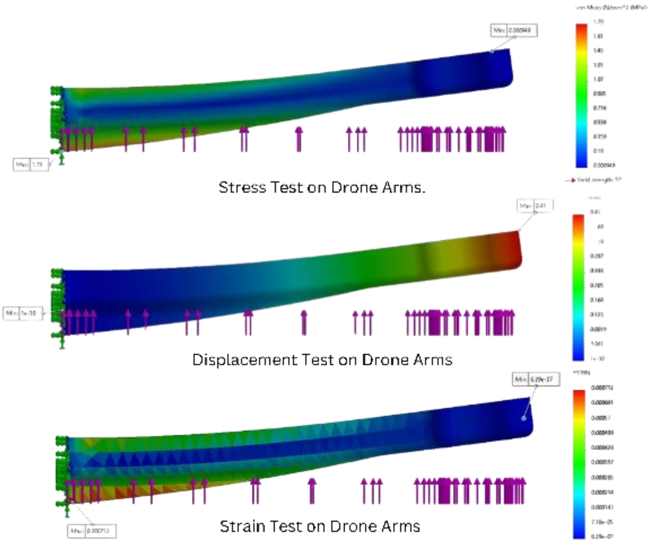


Figure 4: Stress, Displacement, and Strain Test of Drone Arm

Table 1: Static Test Results of Drone Arm

| Static Test Summary (Maximum) | |
|---|---|
| Von Mises Stress | 1.79 MPa |
| Displacement | 0.41 mm |
| Strain | 0.000712 |

In Figure 4, For the Static test for the drone arm, a uniform load of 7.534 N is placed underneath the arm of the drone to simulate the maximum load on the drone, while the starting point of the arm is considered the fixed geometry for this simulation. The simulation results are 1.79 MPa for maximum Von Mises Stress, 0.41mm maximum displacement, and 0.000712 maximum strain for the drone arm. Support under the drone arms is added to lessen the arms' deformation and stress. These supports also help strengthen the battery cage by providing support along the battery cage walls, reducing the risk of the battery cage snapping during flight.

Figure 5, the fixed geometry is placed under each motor slot of the drone while the uniform load of 7.534 N is placed on top of the drone to simulate the weight of the drone affecting the arms. The load of 7.534 N is calculated

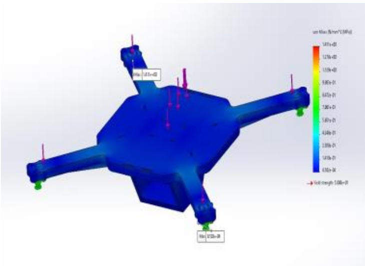

Figure 5: Static Test for Von Mises Stress

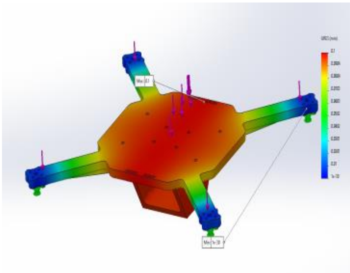

Figure 6: Static Test for Displacement

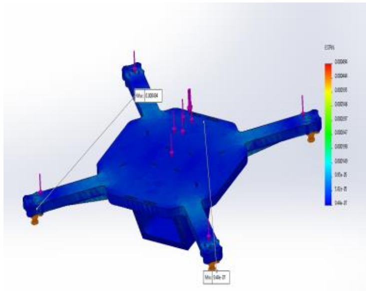

Figure 7: Static Test for Strain.

from the approximated total weight of the drone by multiplying the approximate mass of 0.768 kg by gravitational acceleration. The von Mises stress gathered from the simulation has a maximum value of 1.41 MPa, which can be found near the motor slot.

Figures 5, 6, and 7 show stress analysis. The fixed geometry is applied to the motor slots of the drone, and a uniform load of 7.534 N is applied on top of the drone to simulate the effect of the drone's weight on the arms. The load value of 7.534 N is derived by multiplying the drone's approximate mass of 0.768 kg by the acceleration due to gravity. The von Mises stress simulation results show a maximum stress of 1.41 MPa near the motor slots, indicating the highest stress concentration within the structure.

In the displacement simulation, under the same loading conditions, the maximum displacement recorded is 0.1 mm, occurring at the center of the drone, as highlighted by the red area. In contrast, the blue regions represent minimal displacement.

The results from the static strain analysis reveal that the body experiences a strain of 0.000494 under the applied load, corresponding to the weight of the drone's components. This indicates that the body design effectively distributes the load across the structure, preventing stress and strain concentration in localized regions. Proper load distribution is critical for ensuring flight stability, as it minimizes structural failure risk and enhances overall operation performance.

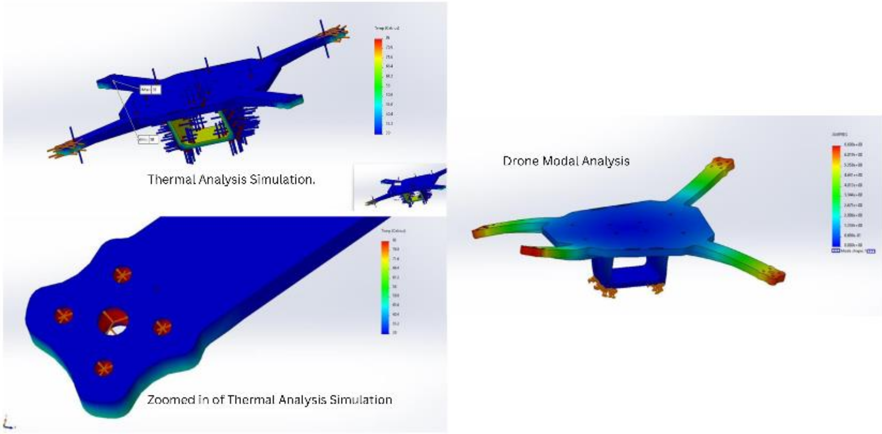


Figure 8: Thermal and Modal Analysis

In the thermal analysis in Figure 8, the drone focuses on evaluating heat dissipation from key components, including the motors and battery. The heat sources are positioned at the motor slots and battery compartment, with temperatures based on manufacturer specifications. The XING 2506 FPV Motor has a maximum operational temperature of 82°C, while the battery temperature is set at a maximum of 70°C. The ambient temperature for the simulation is 30°C. In addition to thermal analysis, a modal analysis was conducted to determine the drone structure's natural frequencies and mode shapes.

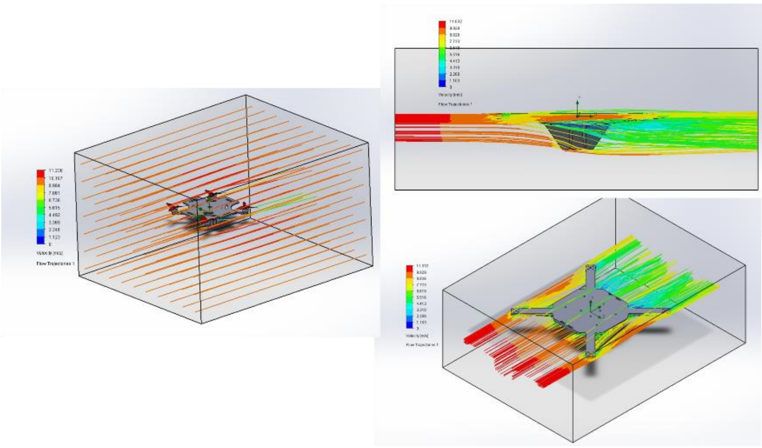

Figure 9: Flow Simulation of Drone

In Figure 9, the drone's computational fluid dynamics (CFD) simulation was conducted to evaluate its external airflow characteristics under standard atmospheric conditions, with air as the medium. A 10 m/s inlet velocity was applied to the front of the drone, allowing airflow to move across the model from front to back. The results indicate that the maximum velocity reached 11 m/s, as represented by high-velocity streamline regions, while the minimum velocity dropped to 1 m/s, particularly at the rear of the drone and adjacent to the battery cage. The symmetrical design of the drone contributes to even weight distribution, ensuring stability and balance while enabling the motors to receive a consistent air supply for cooling. Additionally, the battery compartment experiences continuous ventilation, reducing the risk of thermal buildup and overheating.

However, flow turbulence was observed at the rear of the battery slots, where airflow interacts with structural supports. These findings provide valuable insights into the drone's aerodynamic efficiency, stability, and thermal management, ensuring its optimized performance under real-world operating conditions.

### *4.2. Material & Printing Parameters*

The material used for the drone body is ABS+ from eSUN (2024). The filament's material properties are listed below for computations, simulations, and printer settings.

Table 2: ABS+ Specifications

| Material Property | Value | Material Property | Value |
|---|---|---|---|
| Density (g/cm$^3$) | 1.06 | Extruder Temperature (℃) | 230 – 270 ° C |
| Heat Distortion Temperature ° C | 636 | Bed Temperature (℃) | 95 – 110 ℃ |
| Melt Flow Index (g/10min) | 15(220℃/10kg) | Fan Speed | 0% |
| Tensile Strength (MPa) | 40 | Printing Speed | 40 – 100 mm/s |
| Elongation at Break (%) | 30 | Heated Bed | Required |
| Flexural Strength (MPa) | 68 | Recommended Build Surfaces | High-Temperature Tape, PVP Solid Glue |
| Flexural Modulus (MPa) | 1203 | Elastic Modulus (MPa) | 2000 |
| IZOD Impact Strength (KJ/m$^2$) | 42 | Poisson’s Ratio | 0.4 |
| Durability | 8/10 | Shear Modulus (MPa) | 1750 |
| Printability | 8/10 | Compressive Strength (MPa) | 50 |

Table 3: Infill Type Comparison

| Infill Type | Infill Density | Printing Time | Mass |
|---|---|---|---|
| Grid | 85% | 6h 38m48s | 354.495g |
| Triangles | 85% | 6h52m18s | 354.548g |
| Tri Hexagon | 85% | 6h41m14s | 354.485g |
| Honeycomb | 85% | 54h14m40s | 814.945g |
| Lines | 85% | 6h44m27s | 354.676g |
| Octet | 85% | 6h48m47s | 354.666g |
| Cubic Subdivision | 85% | 6h10m51s | 305.911g |

Due to time constraints (see Table 3), the honeycomb infill pattern is not as viable as the infill pattern for the drone. Grid infill pattern at 85% infill density is considered for the 3D printing of the drone model with an accompanying mass of 354.495g and an approximate printing time of 6hrs 38mins 48s.

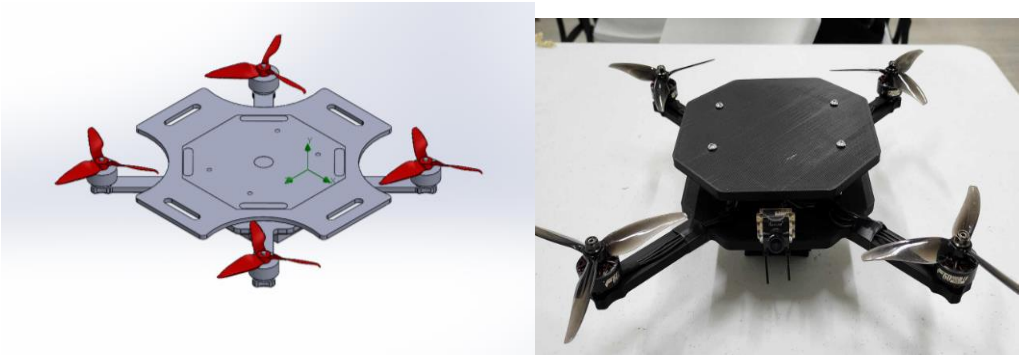

Figure 10: Initial Design vs Actual Printed Design

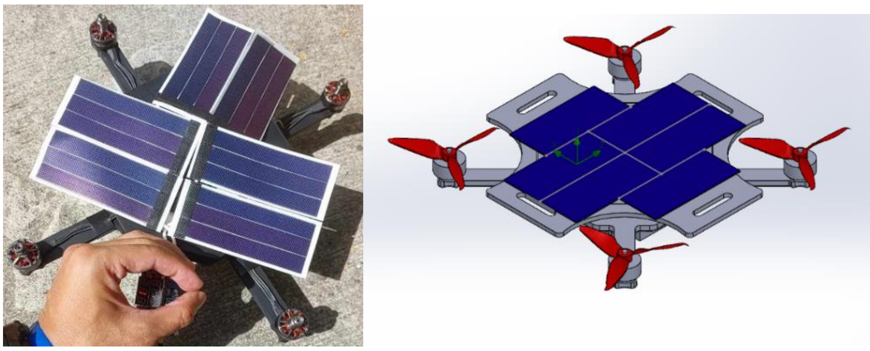

Figure 11: Final Drone Assembly with Solar Panel

*4.3. Analysis of the Drone's Solar Charging Performance*

Evaluating the drone’s charging capabilities demonstrates that the solar panels effectively generate a voltage output between 23V and 24V under standard sunlight exposure conditions. During prototype testing, the current output was measured at approximately 0.1A. The observed charging behaviors indicate that the solar panels successfully transfer energy to the battery, albeit at a limited rate, due to environmental factors, panel efficiency, and the energy conversion characteristics of the system.

Experimental results also highlight the deviation between the theoretical specifications of the solar panels and their actual performance in real-world conditions. Variability in solar irradiance, temperature effects, and panel orientation contribute to fluctuations in power generation. Despite these variations, the prototype demonstrated a measurable increase in battery voltage within a few minutes of exposure to sunlight, confirming the viability of solar-assisted charging. Further optimization of the panel placement, maximum power point tracking (MPPT) efficiency, and energy storage integration could enhance overall charging performance and extend the drone’s operational endurance.

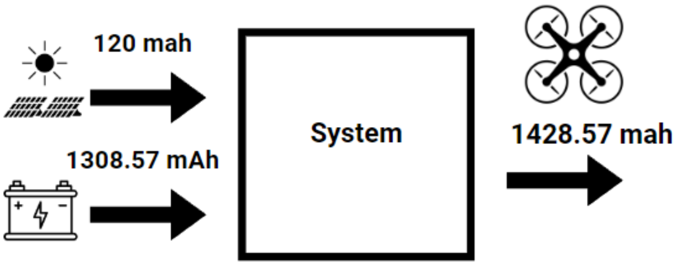


Figure 12: Actual Energy Balance Diagram of Drone

The calculations indicate that under optimal solar exposure, the drone gains a small but measurable increase in energy storage from solar charging. However, given the limited panel output, the additional flight time per charging cycle is approximately 52.2 seconds for 30 minutes of charging using a solar panel. This suggests that while solar power can supplement battery life, it is insufficient as a primary power source without further efficiency improvements, such as increasing panel surface area, optimizing energy conversion via MPPT controllers, and reducing energy consumption through advanced flight control algorithms.

## 5. Conclusions

Finite element analysis (FEA) conducted using SolidWorks 2020 validates the structural integrity of the drone framework. The static stress analysis (Figure 4) indicates that the highest stress concentration occurs near the motor slot within the drone arm, attributed to stress risers formed by the presence of mounting holes. These holes introduce localized reductions in structural stability during the simulation. However, in the physical assembly, these voids are occupied by fasteners securing the motor, effectively mitigating stress concentrations and redistributing loads. For the displacement analysis (Figure 5), the maximum displacement is observed at the geometric center of the drone, coinciding with the location of the primary components. The recorded displacement is approximately 0.1 mm, which is negligible in terms of structural deformation and does not significantly impact drone performance.

Additionally, computational fluid dynamics (CFD) simulations were performed with an imposed airflow velocity of 10 m/s to analyze aerodynamic behavior. Empirical testing further revealed that the internal infill density substantially influences the drone's overall weight and vibrational characteristics. A comparative analysis between 50% and 85% of infill configurations demonstrated significant variations in vibrational response during the landing phase. The increased infill density corresponded to a higher mass, leading to amplified vibrational amplitudes. Mass measurements indicated that a 50% infill structure weighed approximately 250 g. In contrast, an 85% infill configuration resulted in a mass of 350 g, signifying a 100 g increase due to a 35% rise in infill density. The performance of the solar-powered drone was evaluated by testing the ability of the solar panels to charge the onboard battery. Although the charging effect was not highly significant, experimental results confirmed a measurable flow of electricity into the battery. After 20 minutes of direct solar exposure, the battery voltage increased by 0.1V, demonstrating the feasibility of solar-assisted charging. While this increase is relatively small, further optimization of panel efficiency, exposure angle, and maximum power point tracking (MPPT) settings could enhance energy absorption and conversion.

Flight testing and experimentation revealed several key findings. A functional solar charging system was successfully designed and integrated into the drone, with the circuit wiring of the solar panels and the solar charge controller playing a crucial role in stabilizing and supplying power to the system. The optimal components were selected to maximize space efficiency and ensure a consistent energy supply by evaluating various solar panel configurations and charge controllers. The solar charge controller effectively converted fluctuating solar energy into a stable power source. Overall, implementing a solar power system successfully extended the drone's flight duration by supplementing the battery with an additional energy source. While further optimization and testing are necessary to enhance efficiency, the results demonstrate the potential of solar-powered drones for extended and sustainable operations.

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