Atmospheric Impact on Solar Cell Efficiency

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Abstract

Since they are constantly exposed to the elements, solar arrays need to be properly configured to extract the optimal amount of power for any craft. Previously, it has been found that different atmospheric conditions work in tandem to either increase or decrease the measured efficiency of monocrystalline or polycrystalline solar cells. In this study, we analyzed how varying atmospheric conditions impact the efficiency of solar cells to generalize a model for the optimal solar cell configuration depending on the target environment and energy needs. From our analysis, we found that for the most part in high atmosphere, especially in low pressure environments, polycrystalline solar panels were more efficient than monocrystalline. However, due to their higher efficiency, especially with shorter light frequencies, monocrystalline would be better if proper heating was provided.

Introduction

With their zero-emission status as well as their sustainability, solar panels are often used to power various satellites, probes, or UAV. As such, the solar panels often experience similar extreme atmospheric conditions as these vehicles. Out project, SOLAR (Solar Optimization for Launch and Atmospheric Research), aims to figure out how these different atmospheric conditions (atmospheric composition, ultraviolet radiation, temperature, humidity, luminosity, or other light levels) impact the efficiency of monocrystalline and polycrystalline solar panels. Through this experiment, we hope to be able to find the optimal configuration of solar panels depending on the solar panel type.

We hypothesize that the main impacts on the efficiency of a solar panel are the operating external temperature, the bandgaps of each solar cell, the net coverage of a cell in a panel, the density of the atmosphere, the angle of panels relative to the sun themselves, and the current composition of light.

To determine what affects solar panel efficiency, we will measure atmospheric humidity, UV, temperature, luminosity, and light composition, at varying altitudes. By then measuring the differences in voltage output due to these variables between the mono and polycrystalline solar panels, we will be able to derive the exact impact that each of these variables has on the efficiency of the solar panels.

Previously, Benghanem et al. found that the higher the level of solar radiation was, the more efficient the polycrystalline solar panel was relative to the monocrystalline with the polycrystalline having a drop of only 9% while the monocrystalline had a drop of nearly 21% in terms of power output. Furthermore, the polycrystalline solar panels tended to be more resilient towards high temperatures than the monocrystalline solar panels with the polycrystalline only having a drop of 14% while the monocrystalline had a drop of around 16% in terms of power output.

Moreover, in their research, Sarmah et al. found that an angle of around 26 degrees when at sea level was the most efficient for finding the optimal power output. However, due to the differences in their situation versus ours (on the ground vs on a craft), we likely will find different information about the optimal angle for a solar panel. Additionally, in their data, it was found that the lower the humidity, the more efficient the solar panels were with the efficiency roughly following the equation: $y = -0.21x + 20.797$ with y representing the efficiency and x representing the humidity. Similarly, in their data, they found that the higher the wind speed, the more efficiency the solar panel with the efficiency roughly following the equation $y = 0.2784x + 18.367$ with y once again representing the efficiency and x representing the humidity

Overall, based on the results of this project, the exact composition of the solar cell configuration (in terms of bandgap, solar cell makeup, layering) should be able to be determined based on the mission objectives. With this, optimizing power for various satellites, aircraft, or probes in terms of power production should become easier with a higher FOS.

Methodology

This study presents the design, development, and testing of our DemoSat payload to evaluate solar panel output against atmospheric effects at altitudes ranging up to 100,000 feet. The methodology includes system design, sensor integration, ground testing, and data analysis.

System Design

The payload was required to fit the constraints of an 800g mass limit, $500 budget, and to solve a specific problem. One challenge our group took on was to minimize costs by using as many materials and components that we could find in-house, which meant salvaging electronics and structural materials from past projects stored in the lab. In doing so, we were able to save costs and only spend money on the current sensor INA219, which was not available to us in the lab. Structurally, we came up with a hexagonal design to house the sensors and solar panels, chosen for its ability to fit multiple columns of solar panels on as many sides of the DemoSat as possible, which evened out the amount of sun that each panel would face. In order to maintain stability during the flight, we oriented the flight tube vertically along the payload. Our final weight and costs were 623g and $35 spent, which were both well under the requirements.

Sensor Integration

To understand the atmospheric effects on solar panels, we required sensors to measure internal temperature, humidity, pressure, current received from the solar panels, and altitude. We collected external temperature, humidity, UV, and luminosity data. Due to the number of sensors and solar panels, we required two Arduino Unos, one for solar panels and sensors, and one for the sensors that were not taking solar panel readings. Furthermore, in order to maintain the structural integrity of our DemoSat, we situated the different circuits on standoffs directly above the Arduino Unos to have everything physically mounted together. The wiring diagram for the solar panels can be seen in the appendix, Figure 2. The wiring diagram for environmental sensors can be seen in the appendix, Figure 3.

Ground Testing

The four tests that our DemoSat was required to pass to fly were the drop test, stair test, whip test, and temperature test. Our payload survived the three structural tests, maintaining wired connections as well as its structural integrity throughout conditions similar to what it would be facing during launch. The temperature test proved that the electrical components could still function properly while under extreme cold temperatures, as well as the heating elements keeping the inside components at a steady 20 degrees Celsius for optimal sensor function. See Appendix, Figure 4 for graphs of testing data.

Flight Day

On Saturday, March 4th, 2026, at around 7 am, the balloon containing our DemoSat was launched at Deer Trail, CO. The approximate latitude and longitude of the launch location were

39°36'29.8"N, and 104°02'31.1"W, with a starting altitude of 5,600 ft. We successfully recovered the balloon at Arriba Colorado, and our payload retrieved 2 hours and 36 minutes of data. See flight path at Appendix, Figure 1.

Data Analysis

Once the data was obtained, we needed to process the data into a useable format to obtain the results. We utilized the Pandas Python package to make arrays of data and then plotted the raw data as a visual.

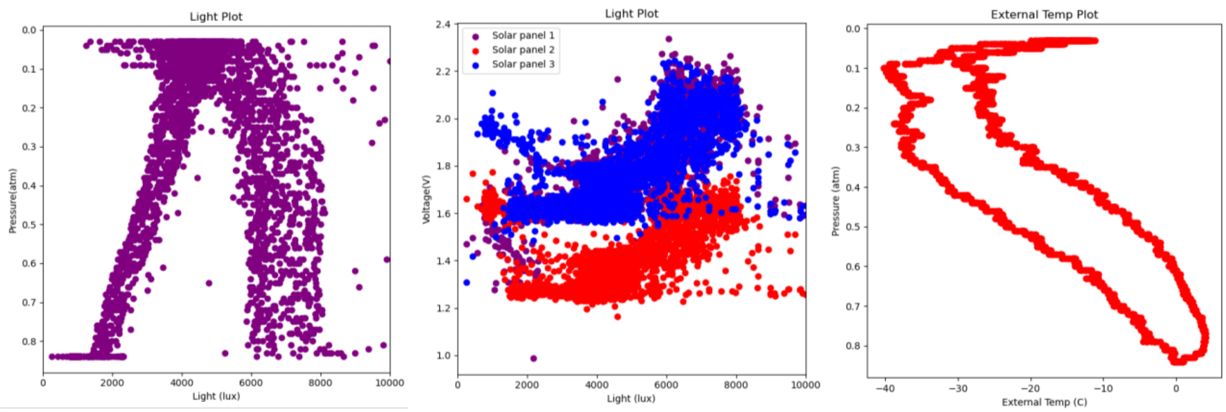


Figure 1: Left (External Temperature vs. Pressure/alt Plot), Middle (Light Values vs. Pressure/alt Plot), Right (Solar Panel Voltages vs Light Values)

As can be seen in Figure 1, the sensors successfully recorded data for the whole experiment, due to the temperature profile exactly matching the temperature profile of the Earth's troposphere and lower stratosphere. Altitude was then able to be calculated simply, using pressure data. This provides a metric which all variables could be plotted against.

Plots of solar panel performance vs. other parameters were also made. See Appendix 5. Trends emerged in graphs such as Solar Voltage vs. Light, however, some plots such as Solar Voltage vs. Altitude did not have any clear trends, due to the number of factors changing with increases in altitude.

In order to account for this, further analysis methods were utilized as listed below. Additionally, UV and Humidity data both ended up being unusable, due to likely sensor failure. Firstly, noisy data was thrown out from the data set. Bad data was determined to be anything that varied more than 2 sigma from the mean, influenced by Chauvenet's Criterion, a criterion commonly used in data analysis to avoid getting rid of good data. Once bad data was rejected, the data was binned into 89 evenly spaced bins. This binned data was then plotted with the mean being the scatter plot point, and 1 standard deviation being the error bars on said plot. This plot can be seen in Figure 2 in the results section. Once the final plot was produced, in order to obtain efficiency estimates, a max and min value of the dataset was calculated, along with the difference between the two for each solar panel. If the solar panel increased by a significant amount more than another during flight duration, it can be considered to be more efficient than the other solar panel at higher altitudes. Further modeling with chi square analysis was attempted, but without a linear or polynomial trend, modeling proved to be outside of the scope of this study.

Results

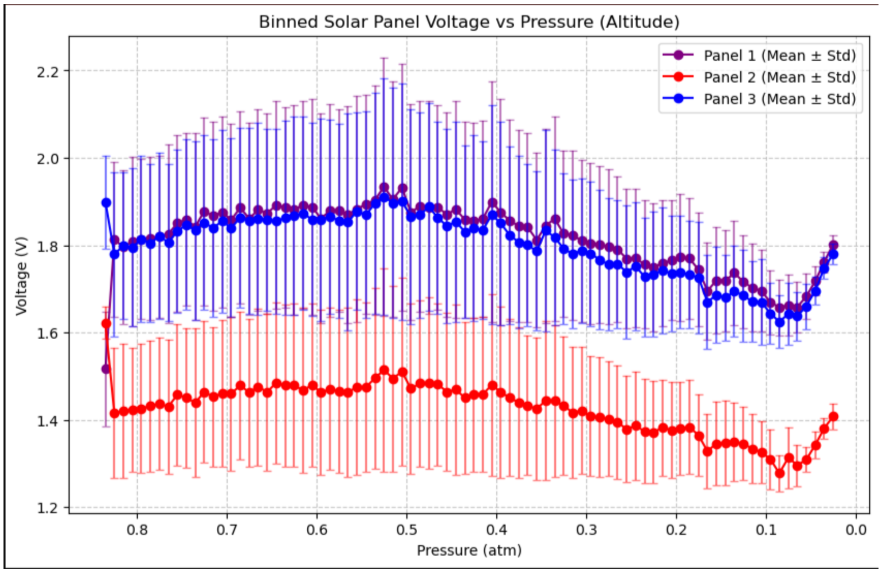


Figure 2: Binned Solar Panel Data vs Pressure (Altitude) Plot

From the final plot of Solar Panel Voltage vs Pressure plot in Figure 2, it is evident that the solar panels exhibit the same general trend of peaking at about 0.52 atm, and then decreasing until the payload reaches stratospheric levels. The exact max was calculated to be at 0.51 +- 0.02atm for all panels. This corresponds to an altitude of 17,600+- 1,000 ft. While we cannot be certain, it is assumed that the solar panels would also follow the trend seen at the far right of the graph and eventually reach a higher peak further into the stratosphere. The found values for max solar panel efficiency differ from what we expected due to numerous factors discussed previously, such as differences in light received by the panels as the sun rose. The efficiency was calculated using a max and min of the original data, filtered with a percentile and excluding noisy data from the beginning. The binned data was not used for this calculation because there was a large baseline that the binned data doesn't account for. With this calculation the results were as follows:

Panel 1 (Polycrystalline): Max V: 2.26 V, Min V: 1.56 V, Range: 0.7V

Panel 2 (Control): Max V: 1.75V, Min V: 1.2V, Range: 0.56V

Panel 3 (Monocrystalline): Max V: 2.22V, Min V: 1.55V, Range: 0.67V

With these results it can be concluded that Panels 3 and 1 are slightly more efficient at lower pressures than panel 3, with these panels seeing a greater increase as the flight went on than the other configuration of solar panel. This tells us that the polycrystalline solar panels work better tend to work better at lower pressures than the monocrystalline solar panels. Furthermore, the monocrystalline solar panels worked better at lower temperatures than the polycrystalline.

Discussion

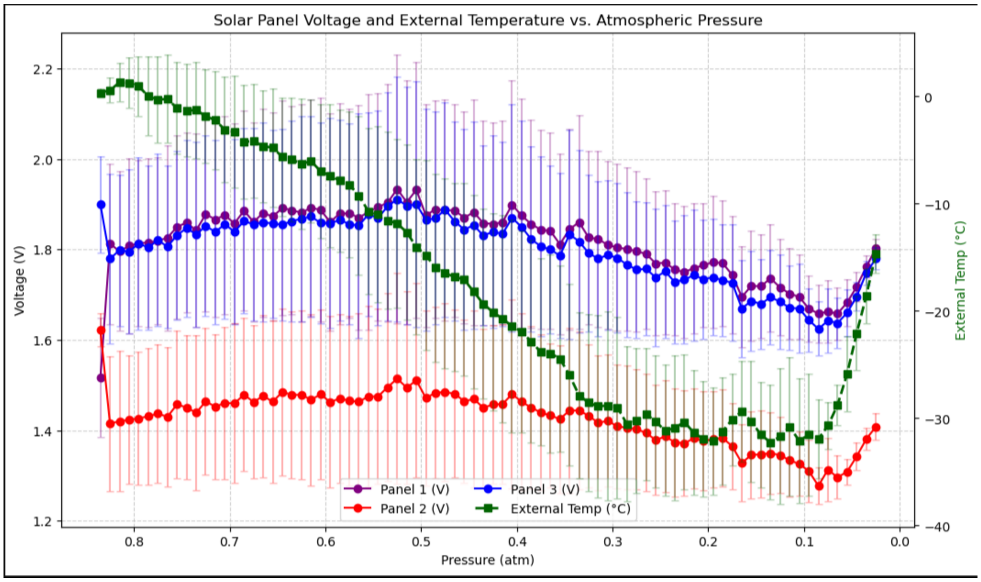


Figure 3: Binned Solar and Temperature Data vs Pressure

Data for how solar panel efficiency varied with altitude did not directly align with our predictions. We expected that efficiency would continually increase with altitude as the solar panels received more light and the temperature got colder. There are many reasons why the data did not match predictions, such as because the launch took place during sunrise, and so as time went on, the sensor received more light, meaning that the light conditions were vastly different during ascent vs. descent, due to conditions outside of altitude. This can be seen in the raw light plot in Figure 1, where the descent on the right sees much more light than the ascent on the right. This means that there will likely be a higher increase in light values due to time of day than the light increase seen due to rise in altitude, inflating the efficiency of points taking during the latter half of the flight. Additionally, the lower angle of the sun can hit the solar panel more directly and also increase values to light levels not normally seen. This could be corrected for in future experiments by modeling light levels as the day increases normally and normalizing for this, or by launching the payload at a time closer to noon, where there will be less variation.

Another impact that could decrease efficiency at high altitudes is the shadow of the balloon. The balloon gets progressively bigger as it gets higher due to atmospheric pressure drop and therefore casts a bigger shadow on the payloads beneath, which can significantly alter the light/voltage received. This is harder to correct for, other than changing the placement of the payload or launching it on a completely different vehicle. The massive error bars are both due to the constant movement/spinning of payloads being launched in this form, and that the binning is averaging both an ascent and descent, that had significantly different conditions due to change in time of day. This could also be accounted for in future experiments via modeling or possibly checking data from the ascent and descent exclusive of each other, though a consistent time parameter would be necessary for this.

Finally, as can be seen in Figure 3, there is a noticeable effect of temperature on the payload. There is a general increase in efficiency as temperature decreases, but not significantly. There were likely other components that affected this result, such as the sensor's efficiency being reduced in the cold. This could be corrected by improving insulation and heating elements inside the payload. Overall, future research should be done with all the factors mentioned, to further constrain and confirm efficiency findings.

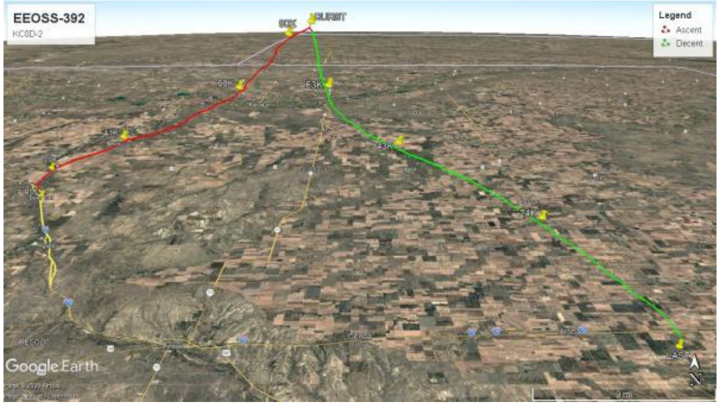
References

392/393 COSGC spring flight - recap. EOSS. (n.d.). https://eoss.org/node/5884

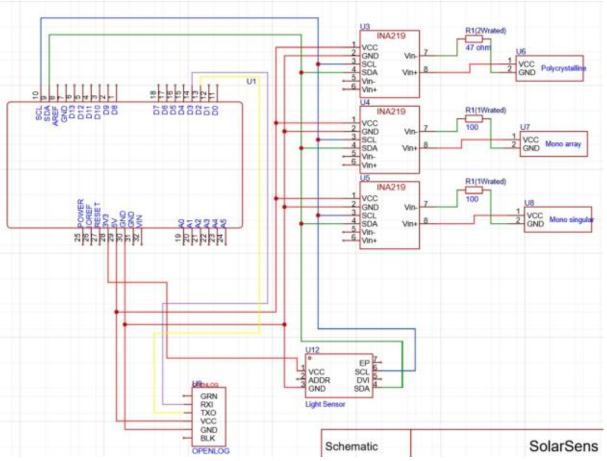
Benghanem, M., Haddad, S., Alzahrani, A., Mellit, A., Almohamadi, H., Khushaim, M., & Aida, M. S. (2023, October 13). *Evaluation of the performance of polycrystalline and monocrystalline PV technologies in a hot and arid region: An experimental analysis*. MDPI. https://www.mdpi.com/2071-1050/15/20/14831

Sarmah, P., Das, D., Saikia, M., Kumar, V., Yadav, S. K., Paramasivam, P., & Dhanasekaran, S. (2023, December 8). *Comprehensive analysis of solar panel performance and correlations with meteorological parameters*. ACS omega. https://pmc.ncbi.nlm.nih.gov/articles/PMC10733962/

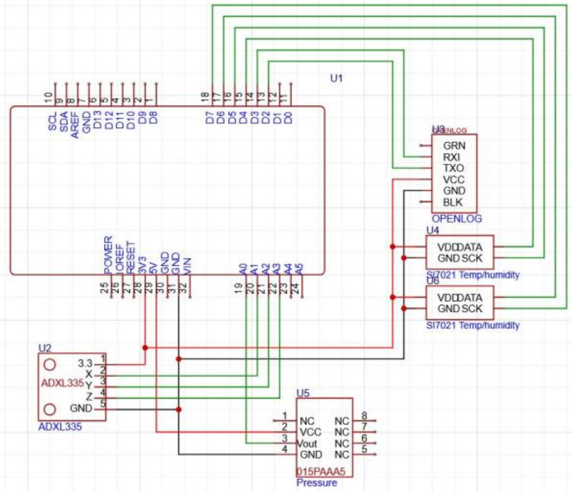
Appendices



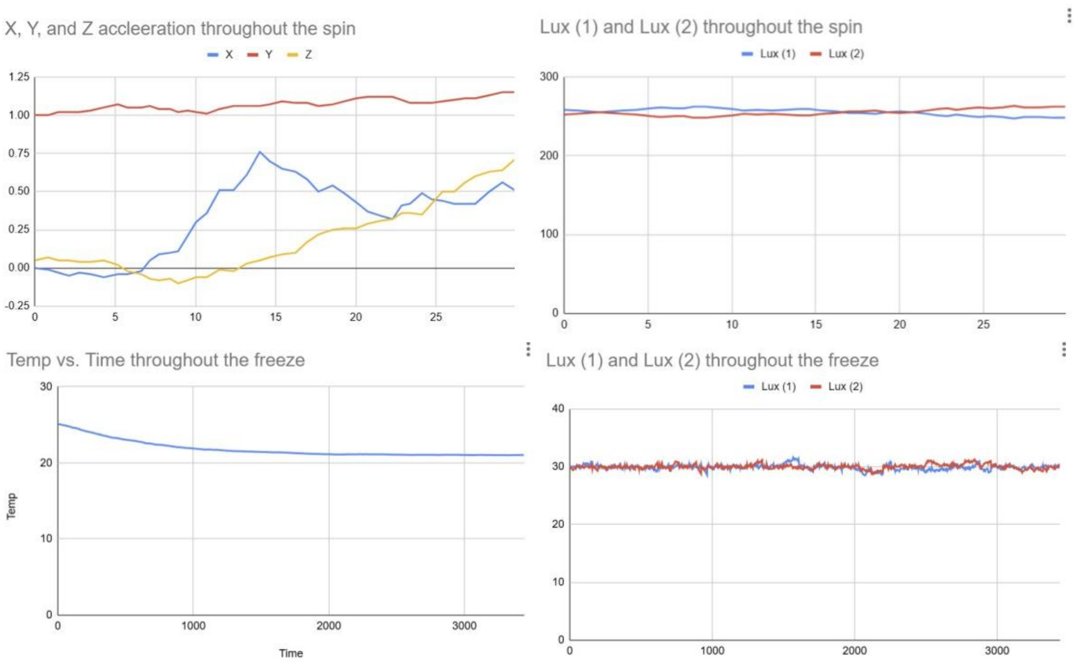
Appendix 1. Flight Path of DemoSat from Deer Trail to Arreba, CO



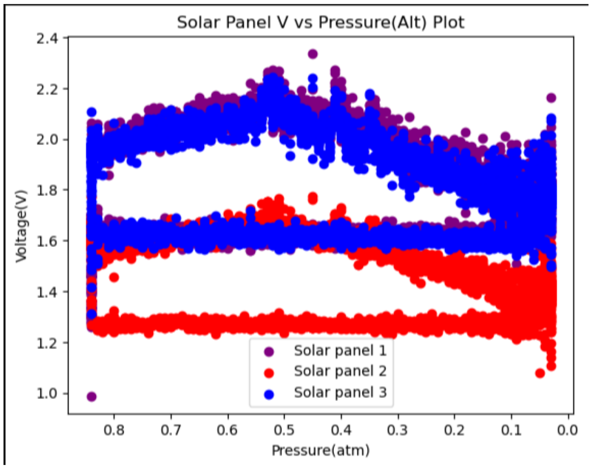
Appendix 2. Electrical Diagram of Solar Panel Sensors



Appendix 3. Diagram of Electrical Board for Environment Sensors



Appendix 4. Testing Data to Verify DemoSat Functionality in Extreme Environments



Appendix 5. Full Data Plots for Solar Panel vs Altitude