Efficiency-Testing a Solar-Powered Payload for Stratospheric Ballooning

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Introduction

Solar panels are arrays of photo-voltaic cells that serve to collect energy to generate electricity, providing an environmentally-conscious method to power electrical devices. Due to their improvement in cost-efficiency, distribution, and ability to provide a continuous supply of energy under sunlight, they can offer an alternative to power microcontrolled units rather than with non-reusable batteries, and therefore, may help improve the longevity of a stratospheric balloon flight.

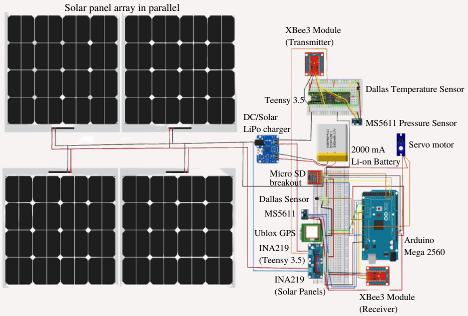
This experiment determined when solar panel arrays were at their most efficient (as a function of altitude) during a stratospheric flight, and characterized which environmental factors contributed to the observed changes in energy production. Due to this, the amount of voltage and electric current flowing through the solar panel array was also measured as the payload ascended to the stratosphere.

Solar-Powered Payload

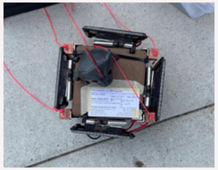
Assembly of HDF and aluminum payload with 6V solar panels secured and deployed.

Inspired by 1U "mock" CubeSat architectures, the payload was built with frames of aluminum and high-density fiberboard (HDF) to protect the internal components, utilizing four 6-volt solar panels, one on each side. Prior to flight, the solar panels were folded and locked with a servo mechanism until it reached an altitude of 500 meters, where torsion springs (located in the hinges connecting the panels to the payload) deployed the array.

The Analysis and Test Microcontrollers



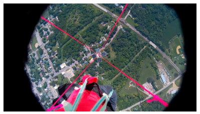
Full wiring diagram of the electric circuit inside the payload, including the Arduino Mega system, the Teensy 3.5 testing unit, and the solar panel array.



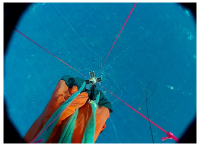
External assembly of the components of the payload, with solar panels folded and locked prior to launch.

A Teensy 3.5 (T3.5) microcontroller was chosen as the solar-powered testing unit, with the goal of continually operating the system and transmitting data. This unit was also connected to a Li-Po charger that was attached with a backup Li-ion battery. Meanwhile, the battery-powered Arduino Mega analysis unit was tasked with recording the environmental conditions that the solar panels were subjected to, and logged the amount of power flowing through the solar array circuit and Teensy testing unit with INA219 sensors. Each unit included a Dallas DS18B20 temperature sensor, a MS5611 pressure sensor, and an XBee 3 radio.

The Flight



Deployment of the solar panel array at 500 meters above ground, at T+112 seconds.

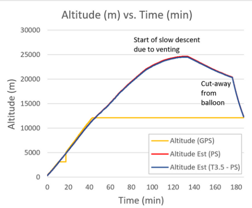


The payload with full sunlight, with the solar panel array reflecting sunlight minutes before balloon separation.

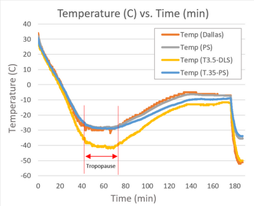
"Solar Operations with Novel Instrumentation Array", or SONIA, was launched on July 15, 2021, with a venting system (as a separate experiment), under a clear sky.

- **T+112 seconds:** The payload logged an altitude of 500 meters above ground, deploying the solar panel array.
- **T+40 minutes:** Light turbulence experienced from wind speed; solar panel array remains unaffected by shade caused by balloon (H = 10900 m).
- **T+49 minutes:** Higher wind speeds start to affect the balloon and payload, forcing SONIA into greater oscillations and receiving occasional shade from the balloon and parachute (H = 12740 m).
- **T+93 minutes:** Turbulence ends. Payload is under full shade from the stratospheric balloon, providing no direct sunlight to the solar panel array (H = 21800 m).
- **T+141 minutes:** Sun angled enough to provide sunlight to the solar panels, with a smaller shadow area from the balloon due to venting periods (H = 23800 m).
- **T+177 minutes:** Vent detaches from balloon; SONIA goes into free fall before the parachute deploys (H = 20100 m).

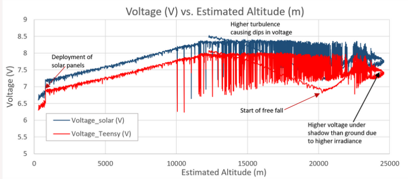
Results

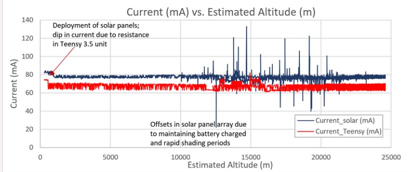


Results from the altitude of SONIA over time. GPS altitude data stalled, MS5611 altitude estimates used.



Temperature measurements from the Dallas DS18B20 sensors (yellow and orange) and MS5611 sensors (gray and blue).





Output voltage and current from the solar panels (blue) and input to the Teensy 3.5 testing unit (red).

Reasons for increased voltage at higher altitudes can derive from greater levels of spectral irradiance, allowing significant solar energy to reach the solar panel array, and which reduce by 27 percent at sea level compared to outside of the atmosphere [1]. Additionally, particles of water, oxygen, and carbon dioxide halve the amount of the IR energy reaching the Earth's surface [2], while the ozone layer absorbs 50%, 90%, and 99% of UV-A, -B, and -C rays, respectively [3]. This data, along with the increased efficiency in solar energy collection at colder temperatures [4], provide an explanation for this behavior in stratospheric altitudes. However, since SONIA was not equipped with a spectral irradiance sensor, it cannot be presented as the definitive cause for this high voltage.

Conclusions and Recommendations

The solar panel array system designed for SONIA provided a significant surplus of energy beyond what was predicted for the Teensy testing unit to work. Therefore, on future flights, it should be possible for solar-powered electronics to perform a greater number of tasks.

It was also shown that, during shaded periods, the solar panels did not wane in their output as they reached higher altitudes, which was theorized to be due to balloon translucency and greater levels of spectral irradiance. For future flights, it would be recommended to include a spectral irradiance sensor, as well as a luminosity sensor and IR/UV ray sensor, to demonstrate if these factors also contribute to the sustained levels in voltage during shaded periods.

Acknowledgements

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