# The Solar Launched Automatic Power System: A Long-Term Solution for Mid-Flight Power Complications

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**The flying of engineering payloads on high-altitude weather balloon launches provides an opportunity to conduct groundbreaking research on the behaviors of the atmosphere at over 100,000 feet above sea-level. However, the main power source of these payloads, disposable batteries, come with their own set of challenges. Disposable batteries tend to die quickly, place additional mass on the already strict mass budget each payload must adhere to, and have the potential to overheat and fail to provide power. We aim to create a solution to the challenges brought on by this power source that can be implemented for other payload projects in the future. The Solar Launched Automatic Power System (SLAPS) is a payload designed to be launched into nearspace, autonomously deploy a solar panel array, and measure the effectiveness of solar panels as an alternative energy source for long duration near-space missions. Several iterations of this payload have been built and flown to advance the understanding of how changes in design can ultimately lead to our goal of alternative power. The chassis of the payload is equipped with monocrystalline solar panels designed to collect power throughout flight, which are deployed during flight and automatically retract after the balloon bursts or is cut down. After flight, post-launch analysis is conducted and will determine how much power our payload was capable of collecting and any unexpected disruptions mid-flight. This paper will present an in-depth breakdown of the structural and electronic components of the payload, followed by preliminary results based on data collected during near-space flight.**

## I. Introduction

The Balloon Payload Program at the University of Maryland, also referred to as the "BPP," is an extracurricular organization open to all majors on campus, in which students have the opportunity to build engineering payloads to be attached and flown on a high-altitude weather balloon launch for research purposes. These payloads range in academic level, from undergraduate freshmen to postdoctoral fellows. The BPP is funded by the Maryland Space Grant Consortium along with other universities in the surrounding area and has organized over 100 launches since its creation in 2003 by Dr. Mary Bowden (Breeden et al., 2019). Members of BPP contribute towards launch logistics and operation, putting significant time towards the preparation of these launch days. Each launch is given a unique name with the format "NS-XX," where the "NS" refers to the term "Near-Space" and the "XX" refers to the launch number, which started with NS-01 in 2004. This program has allowed for unique undergraduate research opportunities in the space field that help to advance students' progressions through college in a number of ways, including the development of hands-on project skills. These skills have helped current and former members advance their careers and education at highly regarded companies and institutions. Members of the BPP have previously presented manuscripts at the Academic High Altitude Conference and have been published through the American Institute of Aeronautics and Astronautics (AIAA), which inspired us authors to submit our findings as well.

A specific payload, titled the Solar Launched Automatic Power System, or "SLAPS," is the focus of this writing. The six authors of this manuscript have been collectively collaborating on this project since September 2021, with the project starting originally as an independent project of Madelaine Lebetkin's during the summer of

2020. The authors of this manuscript are all undergraduate students studying various engineering disciplines. The concept of SLAPS is to autonomously deploy a solar panel array contained within the payload structure and to measure the power collection of solar panels during near-space launches with the BPP.

The idea of the payload was created after an observation of the main power source of payloads in the program: disposable batteries. Disposable batteries are the power source of choice for most payloads due to their general accessibility, which can't be said about all payload components given the continuing electronics shortage, and are also simple to incorporate into electronic schematics. Disposable batteries, while convenient, come with a set of challenges to every payload project. A high-altitude balloon launch typically travels through the air for well over an hour, sometimes several hours, and many payloads tend to run electronic functions throughout the duration of flight (Breeden et al). This longevity of run time depletes battery life quickly, requiring constant replacement of batteries between in-lab testing and flight. The battery mass also impacts the already-strict mass budget each payload must adhere to, especially when multiple disposable batteries are used on a payload. While a payload is traveling on a high-altitude balloon launch, the air temperature can change dramatically, which can cause the internal battery chemical reactions to fail (Deng et al., 2019). The varying temperature can make disposable batteries unable to provide power, negatively impacting the ability of payloads to collect data. Over the course of the project, there have been three distinct iterations of SLAPS with a fourth currently being built.

## II. Previous Payload Iterations

### SLAPS 1.0

Once the concept of a solar panel deployment mechanism was developed, Lebetkin collaborated with Grace Warznak and others to design the first iteration of the SLAPS payload. The initial design process took place over Zoom calls and virtual chat-rooms. During this time, a majority of classes at UMD were completely online, and the buildings and labs on campus had significantly limited capacity. The BPP labs were limited to one person at a time, but after the initial design review, the team members who lived on or near campus came in on a staggered basis to start constructions.

Due to the severely limited capacity in the lab and the general inexperience of most of the members on the SLAPS team, people were required to teach themselves how to code in Arduino; how to properly design, correctly build, and safely solder the circuit; how to use a 3D printer; and how to build a payload according to the BPP and FAA requirements. The introductory engineering courses were mostly, if not entirely, online for the majority of the team, so these hands-on design, build, and test opportunities were missing from the members' curriculum.

The team held a critical design review for the payload in mid-Winter to fulfill BPP's requirements for building and flying a payload. The payload was constructed over the course of the next few months, and SLAPS 1.0 was ready to fly for the first time on NS-97 in April of 2021.

When the SD card was retrieved following recovery from the launch, the team discovered that the data failed to record. Along with that, the servo would overheat and automatically shut off while trying to lift the heavy solar panels so as to not damage the servo's hardware, so the panels did not retract until the force from falling put the panels back in their undeployed configuration. The payload was also over two pounds, and a lighter solar panel configuration would be necessary for the addition to future payloads.

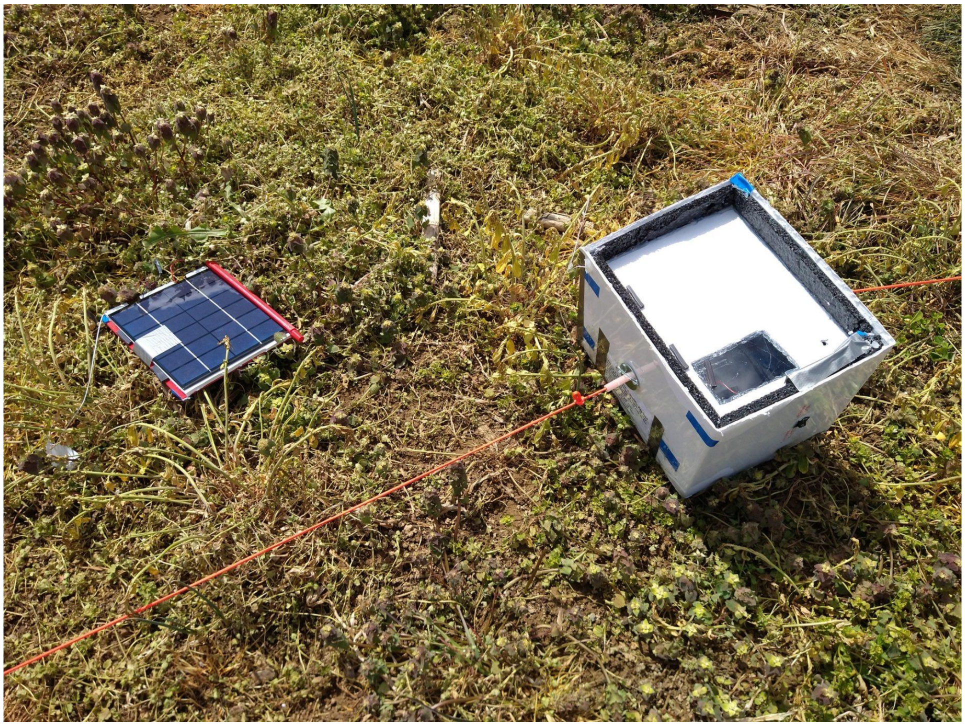


**Fig. 1 - SLAPS 1.0 Field Recovery After NS-97**

### SLAPS 1.5

After the flight of SLAPS 1.0, the electrical components of the original payload needed to be upgraded to consistently deal with issues that arose on SLAPS 1.0. Data recording failed on the first flight, therefore this was prioritized on the second launch. The software was entirely rewritten to deploy the solar panels with an emphasis on ensuring data safety even in the event of power failure and thoroughly tested to ensure data was captured. Structurally the payload was not changed, however due to issues from SLAPS 1.0 the payload was flown only with one solar panel. The team hoped to implement magnets to help the remaining solar panel deploy, but this idea was scrapped for our final launch. During the second flight of SLAPS 1.5 on NS-104, the solar panel was detached from the payload due to material failure.

## III. Supplemental Payload

### SLAPS Lite

After flying SLAPS 1.0 and 1.5, the team shifted towards designing the current iteration of the payload: SLAPS 2.0. During the development of SLAPS 2.0, one of the curiosities the team had was how the angle of the solar panels relative to the payload would affect the power generated by the solar panels. The obvious answer would be to set the solar panels perpendicular to the payload, resulting in higher power generation. Although, during a balloon flight the payload is tossed around in free space, causing the payload's orientation to vary and the balloon casts a shadow that could affect performance. To try to determine if a certain solar panel configuration would bring in a significant amount of power compared to a different configuration, the team built an iteration of the payload called "SLAPS Lite."

**Fig. 2 - SLAPS Lite**

The SLAPS Lite payload was relatively small compared to most payloads, weighing in at around one pound, much lower than previous iterations closer to three pounds. SLAPS Lite was designed as a trapezoidal prism with solar panels attached on the top, bottom, both side faces, and both faces at 45 degree angles. Unlike previous iterations of the payload, the electronic components were rather simple and consisted of the following: a set of 6 solar panels, current sense resistors, a microcontroller, and a switch. The electronic schematic is as follows:

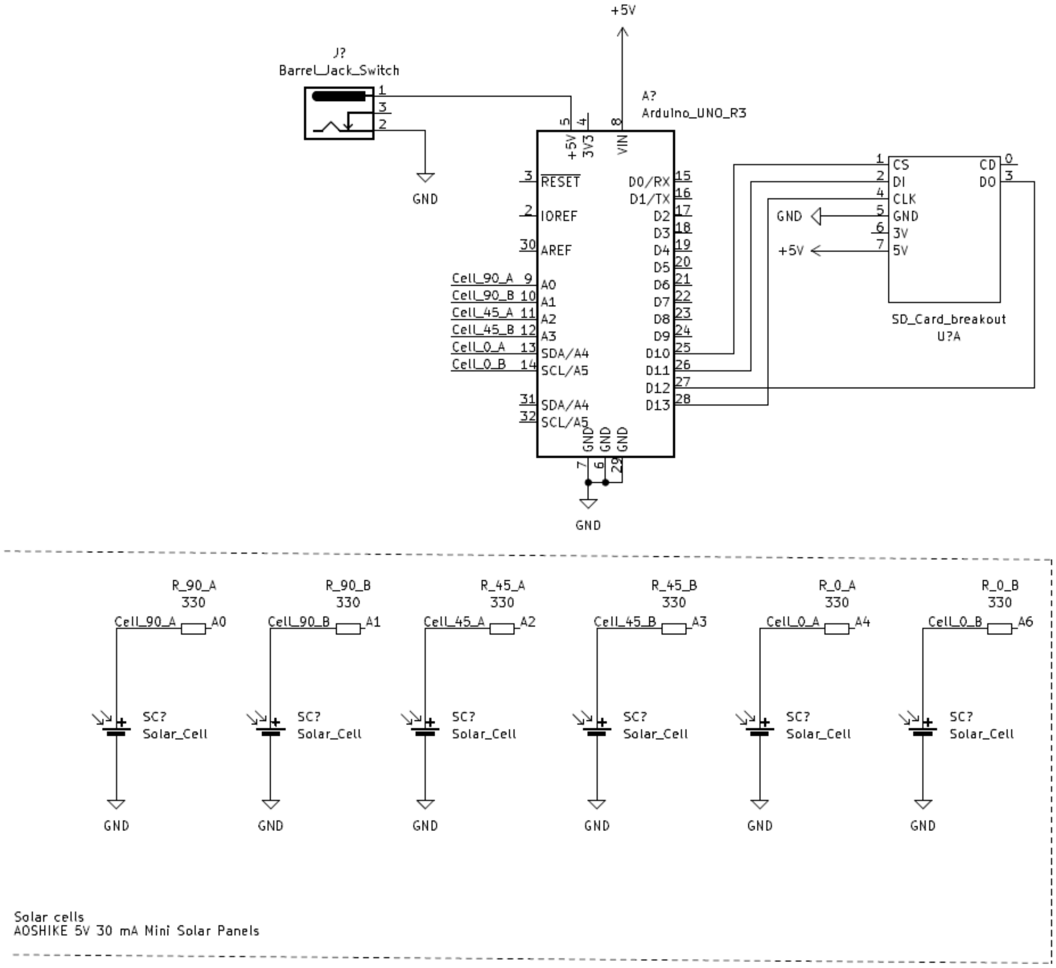


**Fig. 3 - Electronics Schematics for SLAPS Lite**

During the development of SLAPS Lite, the team picked out a pack of solar panels to use on the payload that were flown on NS-110 in the Spring 2022 semester. The original panels were picked from an unknown retailer online without a datasheet, and after the first payload experienced issues with the electronics, the team decided to purchase a more reliable solar panel with a known datasheet to refly the configuration on an upcoming launch, NS-100.

## IV. Current Payload Iteration

After losing a panel on SLAPS 1.5 alongside a slew of other issues, the team realized that the overall configuration needed to be redesigned to continue to get closer to solving the power issues. The overall concept of SLAPS 2.0 is consistent with previous iterations: the payload will be placed on the flight line and turned on, deploy solar panels after launch initiation, take data continuously throughout the flight, and retract the panels when the payload is losing altitude. A major difference in the SLAPS 2.0 is the configuration of the panels. Rather than having 2 large panels deployed on either side of the payload, the team is implementing a design that will deploy the panels in a fan-like fashion and lock them in place using a push-latch mechanism.

The reason the team chose to deploy the panels in this configuration is to lower the stress acting on the servo. In previous designs the servo deployed the panels with the rotation axis parallel to the ascension of the balloon . This led to the servo overheating, because the servo would try to retract the solar panel against the direction of gravity which increased the strain on the device. With the team's current design, the servo will deploy 4 small solar panels with the rotation axis perpendicular to the ground. Through this method the solar panels are not rotated against the direction of gravity and decrease the stress on the servo.

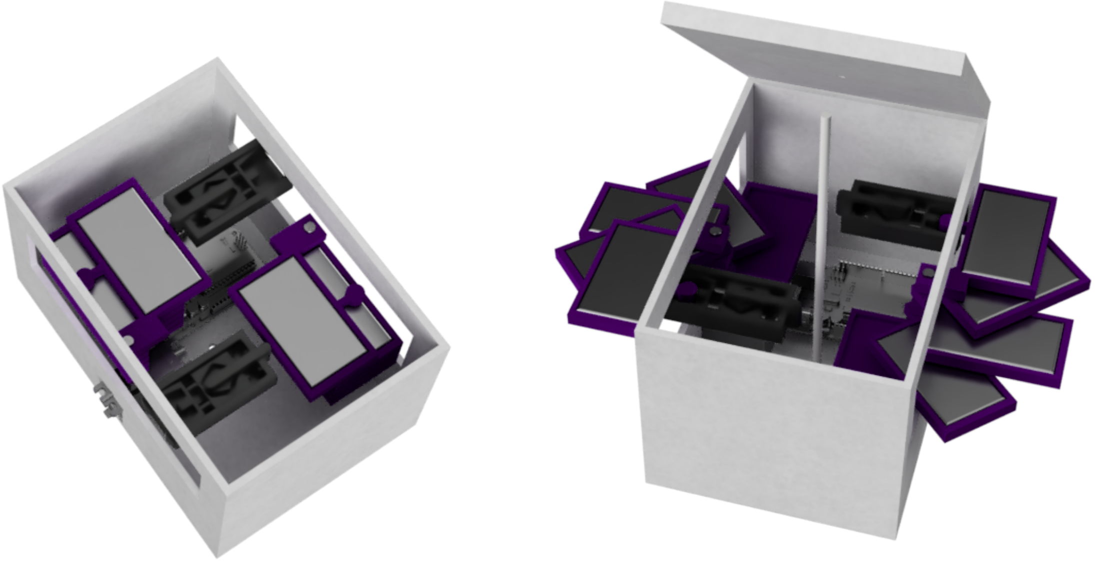


**Fig. 4a - CAD of SLAPS 2.0**

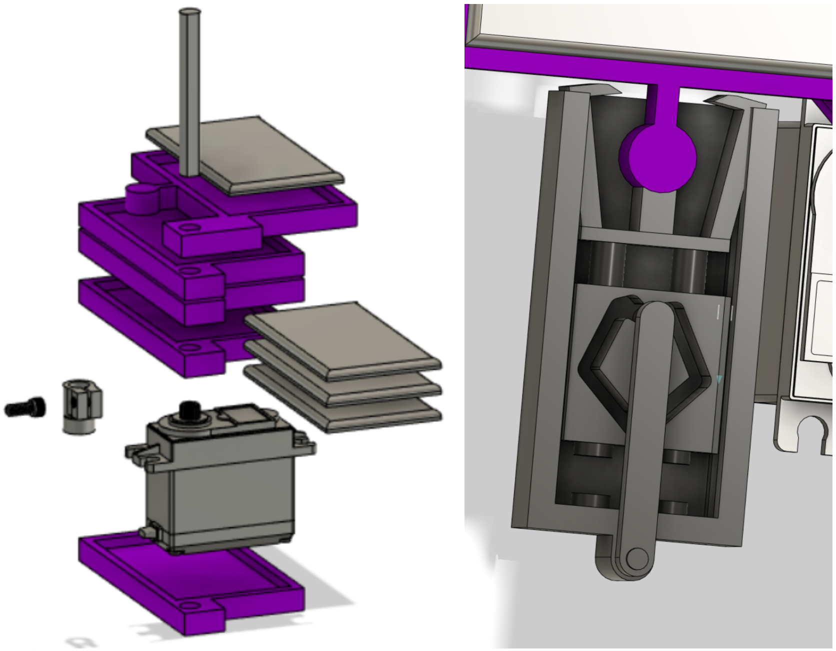


**Fig. 4b - CAD of SLAPS 2.0 Deployment Mechanism**

With this design came the disadvantage of requiring a more complicated system for deploying the panels. First 3D-printed holders had to be designed for the solar panels to connect them to the servo through an axel. Then in order to rotate the panels together to their proper position the team will use a light fabric or string to connect the solar panels, so when the top one rotates the rest will follow. Finally in order to keep the solar panels in place the team designed a push-push latch that will allow the solar panels to lock into place.

In this design the servo of choice is a Bilda Dual Mode Servo and has a maximum rotation of 300°, a stall torque of 7.9 kg • cm, and a voltage range of 4.8V - 7.4V, which is more than enough power for our mechanism.

Which will be printed from PLA or PETG filament as it provides the highest strength at low temperatures. This mechanism will be installed twice on the payload to provide higher power.

Unlike previous SLAPS iterations, this design includes a custom printable circuit board (PCB) to mitigate any loose wires and damage that affected previous designs, where oftentimes last-minute soldering was required to ensure electrical connections. Consistent with previous iterations, the NA219AID High Side DC Current Sensor will be implemented in this SLAPS iteration as well. There will also be a DS3231M+ Real-Time Clock implemented in the electronic configuration to help maintain data logging consistency, which was not on SLAPS Lite but on SLAPS 1.5 and 1.0.

## New Electronics Configuration

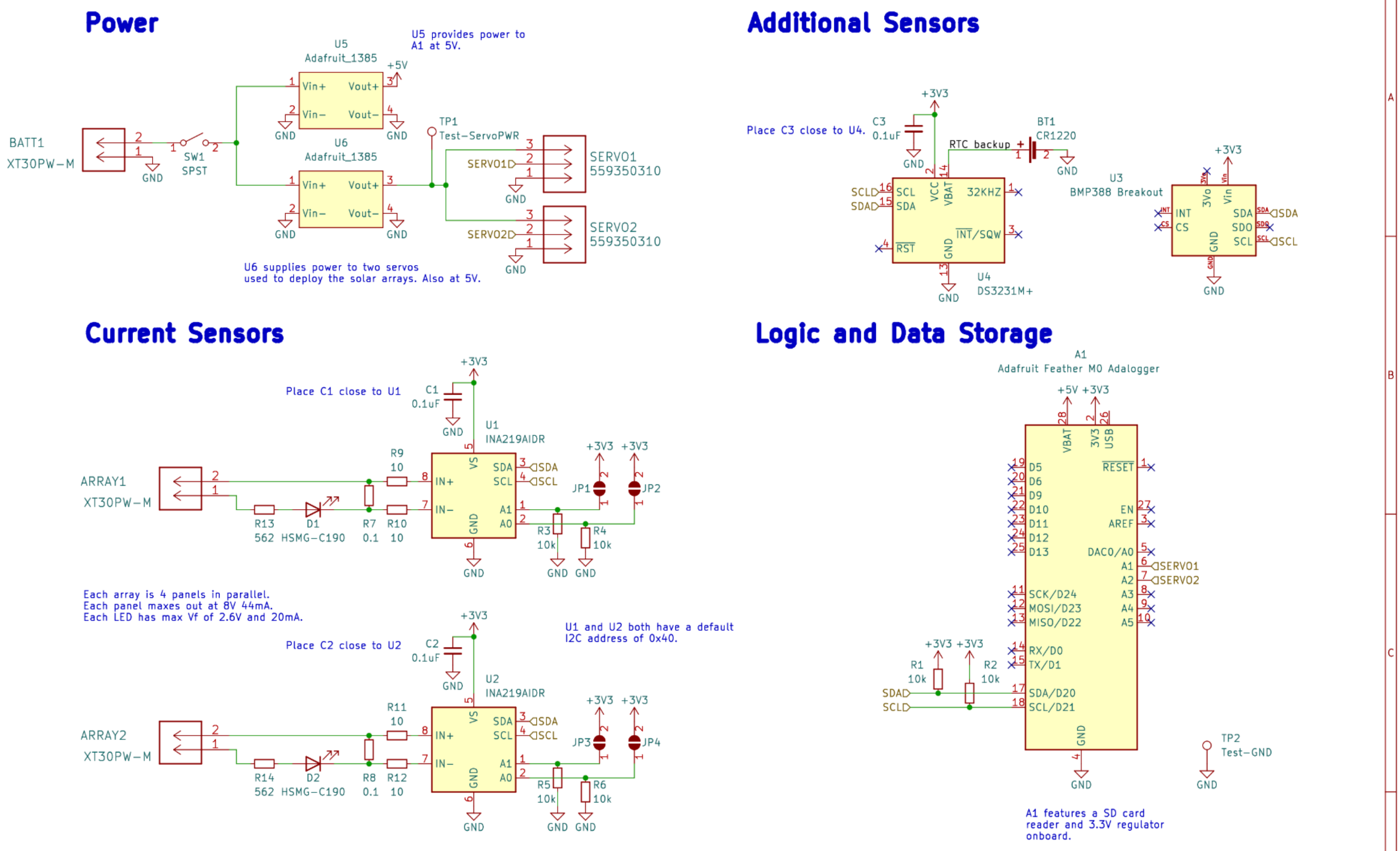
Building off of the work done in previous iterations, SLAPS 2.0's electrical system was designed with the goal of tighter integration while maintaining previous iterations' operational ease of use. Mainly, this takes the form of a custom PCB used to both house and connect the large majority of SLAPS 2.0's electrical system. Key design changes from previous iterations also include using a different microcontroller with increased computational power and the inclusion of a real-time clock. Overall, the SLAPS 2.0 electrical system is a major refinement of previous iterations.

The first consideration made during the design process of SLAPS 2.0's electrical system was the microcontroller and data storage system. In order to avoid data collection issues present in previous iterations, the decision was made to use a microprocessor with greater computational power. After surveying the available options on the market at the time, the decision was made to use Adafruit's Feather M0 Adalogger for a few reasons. The first is that it boasts roughly four times the computational performance of the previously used Arduino Uno (Adafruit Feather). The second is that it integrates the necessary hardware for data logging onto a microSD card. Lastly, its significantly reduced size and weight compared to the Arduino Uno made it an ideal choice for integration onto a larger custom circuit board. Ultimately, this choice allowed for much abstraction of the more complex details.

The second phase of the design was determining the additional sensors and circuits needed to ensure data logging integrity. To accomplish this, the design uses an onboard real-time clock and pressure sensor to accurately keep time and watch for unexpected altitude changes consistent with that of a burst. The real-time clock is used to ensure that each data point can be recorded with an accurate time reference. This is important as time will later be used to correlate each data point with altitude recorded by a separate tracking payload. The pressure sensor will be used to keep watch for conditions that are consistent with the balloon bursting as any sudden, positive pressure changes would indicate that the payload is in freefall. This will allow the payload to retract its solar arrays shortly after an unexpected burst which will help minimize any potential damage that may be caused by the chaotic post-burst conditions.

The third phase of the design was determining specifically how the power of each solar array would be measured. Previous iterations of SLAPS had used the INA219 due to its accessibility in breakout board formats. Due to the team's familiarity with this sensor and its relatively simple implementation, it was chosen as the solar array power sensor for SLAPS 2.0. The design used takes into consideration the specific electrical characteristics of the solar arrays and provides an adequate load for each array. This will enable more accurate power measurement and simple visual troubleshooting of the solar arrays due to the included LED. Ultimately, the INA219 enables the payload to accurately record the power produced by each solar array while maintaining simple integration.

Finally, the last subsystem featured on the SLAPS 2.0 mainboard is the power system. With the number of opportunities to iterate being compressed by the Fall 2022 launch schedule, the team decided to prioritize tested solutions over total system integration. As such, Adafruit's DC/DC converter was chosen due to its simple usage and flight-tested history with the program. This decision aims to reduce the complications caused by other power systems while maintaining high efficiency and reliability in battery-powered applications. The power system will use two separate converters to isolate the array deployment servos from the logic and sensor systems. Both converters will provide 5V to their respective circuits. Additionally, the 3.3V voltage regulator found onboard the Adafruit Feather will provide power to the lower voltage sensors (Adafruit Feather). Ultimately, the use of these specific DC/DC converters will supply the payload with adequate power and efficiency while reducing possible complications during testing and deployment.



U5 provides power to
A1 at 5V.

U6 supplies power to two servos
used to deploy the solar arrays. Also at 5V.

Place C3 close to U4.

Place C1 close to U1

Each array is 4 panels in parallel.
Each panel maxes out at 8V 44mA.
Each LED has max Vf of 2.6V and 20mA.

Place C2 close to U2

U1 and U2 both have a default
I2C address of 0x40.

A1 features a SD card
reader and 3.3V regulator
onboard.

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**Title: SLAPS V2 Mainboard**

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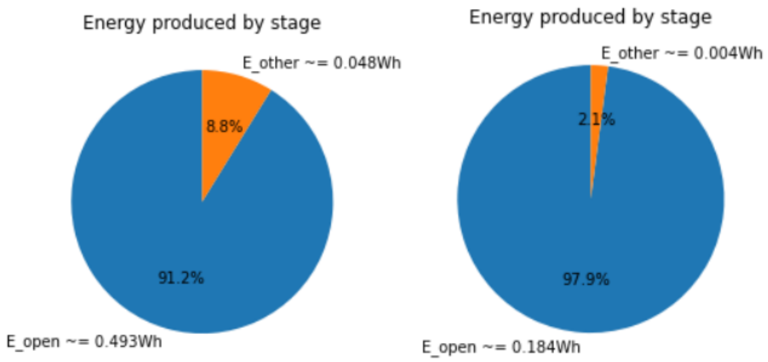
**Fig. 5 - SLAPS 2.0 Wiring Diagram**

### Solar Panel Justification

The SLAPS payload used the same solar panels for the 1.0 and 1.5 versions, but these solar panels proved to be less efficient and much heavier than desired for flight. Because the SLAPS payload is meant to be a stepping stone into an attachment for powering future payloads, the SLAPS team wanted to use panels with better power efficiency and performance. Also, the solar panels are designed to fan out for the 2.0 payload iteration, so smaller, lighter panels are preferable for a lesser torque required on the motor. Polycrystalline solar panels employ the use of many silicon crystals, meaning the electrons are only able to flow within their respective crystal structures. Monocrystalline panels, on the other hand, have only one silicon crystal, giving the electrons much more freedom to move and generating more electricity. This higher efficiency is important for when the solar energy is harnessed to power future payload experiments. For all these reasons, highly-rated 66mm x 37mm monocrystalline panels were chosen for SLAPS 2.0.

## V. Previous Flight Data

Previous versions of SLAPS have flown on five separate flights, being one flight from 1.0, two flights of 1.5, and two flights of SLAPS Lite utilizing two different solar panels. Unfortunately all the data from the flight of 1.0 was lost during flight. SLAPS 1.5 flew and successfully recorded the first data for the payload, it was able to fly on two separate flights of NS-103 and NS-104. The single solar panel on NS-103 was able to capture just over 0.5 Watt-hours of energy.



NS-103 NS-104

**Fig. 6 - Energy produced during NS-103 and NS-104 Figure, Open vs Closed Power**

The most interesting data gained is from the SLAPS Lite iteration, where the same solar panels were placed on different sides of the payload. Figure 1 shows the 2 minute moving average power received by each of the six solar panels during the flight of the payload. As expected on the ground and at lower altitudes, the panels directly in sunlight received considerably more power than the panel on the bottom. Strangely though, as the payload reaches roughly 5000 meters, the power received by the solar panel placed on the bottom of the payload facing the ground reaches the average of all other solar panels. Our theory is that light reflected off the Earth's surface, atmosphere, and clouds becomes bright enough to sustain maximum power on our solar cells. This was observed on both brands of monocrystalline solar panels on SLAPS Lite.

There also appears to be a drop in power received as the payload approached 20,000 meters in altitude. This drop in power at high altitude may have multiple causes. However, the method of measuring voltage in this payload is dependent on a 9 volt battery which was unmeasured, meaning voltage comparison over time may not be accurate. Therefore, the decrease in power seen at high altitude, while consistent over multiple launches, is possible to be caused by the battery's change in voltage.

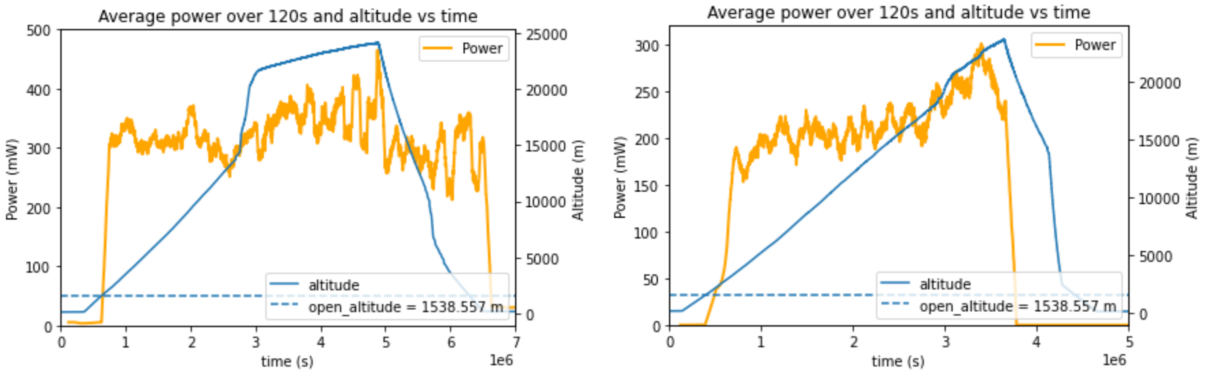


Fig. 7a - Power with altitude on NS-103, NS-104

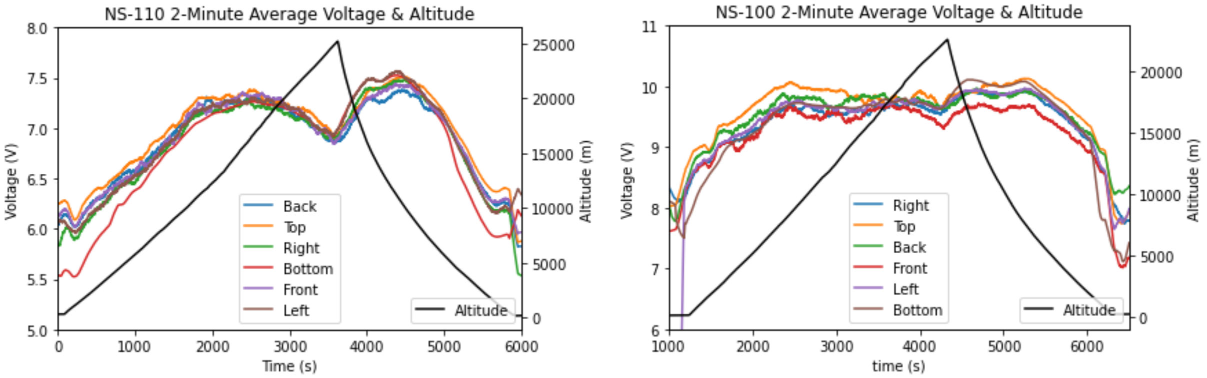


Fig. 7b - Power across individual panels with altitude on NS-110, NS-100

The variability between different brands of solar panels is intriguing, which the team hopes to further test. The cheaper solar panels flown on NS-110 held a more consistent value across panels during flight, leading the analysis to conclude that at high altitudes, the placement has little to no impact on the power generated. However, during the second flight on NS-100 with the higher quality solar panels, the solar panel on the top of the payload maintained the greatest amount of power throughout the majority of the flight. This is what would usually be expected as it is receiving direct sunlight, however the flight of SN-110 this was not as clearly seen. The solar panel on top during NS-110 did maintain the highest power during ascent on average, however other panels were nearly identical and overlapped during the ascent. As each of the solar panels received 44 mA, we can calculate that during the flight, the 6 panels sustained a combined 2.5 Watt-hours with a surface area of 14652 mm$^2$.

## Most Recent Flight Information

The most recent BPP launch at the time of submission, NS-114, took place on December 4th 2022, where SLAPS 2.0 was able to fly and collect data.

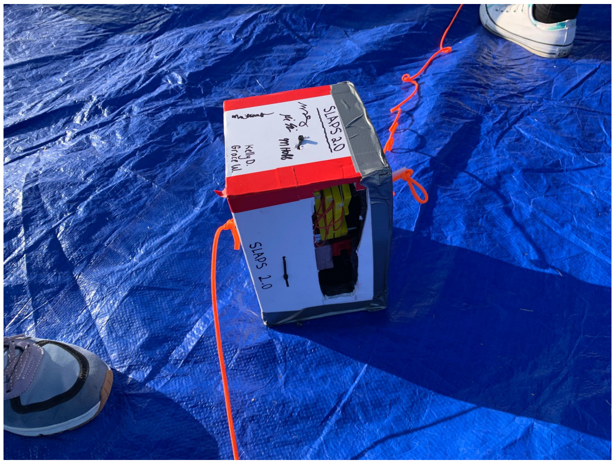


**Fig. 8 - SLAPS 2.0 on NS-114**

Several pre-flight decisions took place, one being building just one solar panel deployment apparatus compared to two, and with only 3 solar panels instead of 4 panels. This design choice was made due to complexities in the latching mechanism. The servo was able to turn on successfully, but the microcontroller only collected data for about 30 minutes. The inactivity of the microcontroller is theorized to be caused by lack of insulation due to the cutout for the deployment mechanism.

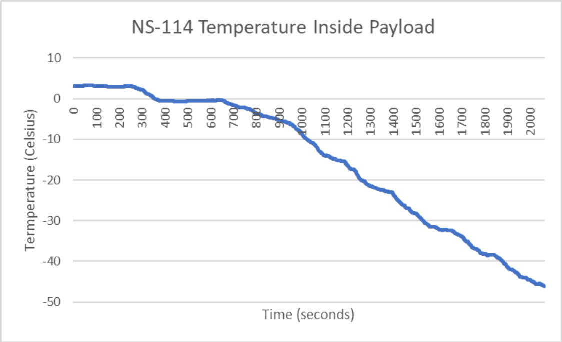


**Fig. 9a - Temperature over time during NS-114**

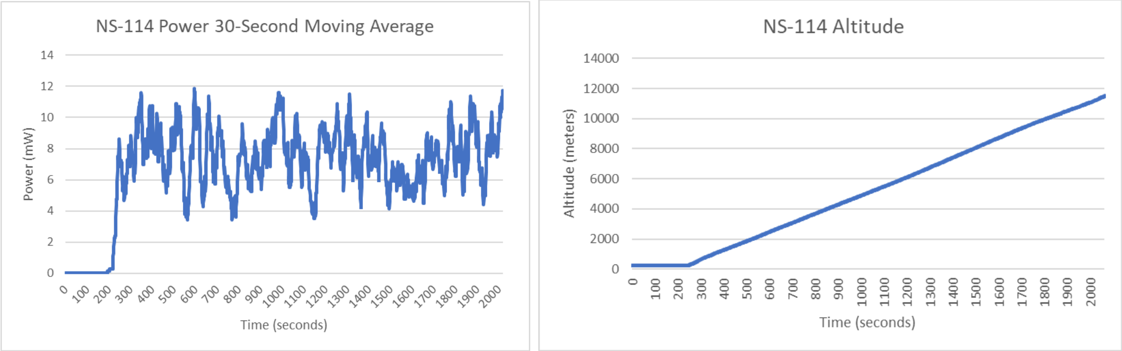


**Figure 9b - Average power collected by the panels and altitude**

## VI. Conclusions & Next Steps

The most significant conclusion that can be made from the data so far, is that at high altitudes, small monocrystalline solar panel angle in relation to sunlight does not make a significant difference. A solar panel facing the Earth's surface is capable of producing equal power as one that is directly facing the sun. The next steps SLAPS will take is to verify data collected so far to present more conclusive evidence on the exact angles, and altitudes that solar panels collect power. Flying the same solar panels on multiple occasions is needed to verify the analysis that was done on the differences between solar panels between NS-110 and NS-100. The team plans to redesign the solar panel deployment mechanism and adjust the payload structure to ensure data collection during the whole duration of the flight. The solar panel deployment mechanism was not quite successful during the first attempt and some amount of solar energy was collected, but the panel mechanism needs some tweaking before being manufactured as an attachment for a separate payload to assist in powering that payload's experiments.

## VII. Acknowledgements

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