High Altitude Solar Survey to Asses Solar Power Output Between Two Collection Methods

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Abstract:

High Altitude Tracking Solar Survey (HATS 2.0) payload for H.A.S.P 2013 proposed to test two solar collection methods to quantify the differences in efficiency between each method at high altitude, compare the data to validate theoretical models for the devices by comparing the results with predictions calculated in advance, and to determine if any of the enhancements are viable for use in small space payloads such as the CubeSat. These methods include two standard flat solar panel mounted on the top of HATS 2.0 payload, and two optimally angled solar panel on a solar tracker, totaling two methods to test solar collection methods for the purpose of contributing research to alternative energy resources.

CONTENTS

1. SCIENTIFIC BACKGROUND

Research on solar collection for energy production is not a new concept; in fact, there have already been several studies comparing the efficiencies of various solar configurations at ground level. Some research has already shown that tracking photovoltaic arrays are estimated to have a gain in energy production as high as 40% over optimally tilted arrays. Ground level solar concentrators generally use a 2-axis sun tracking system, which is considered the default for such systems. Research done by Gomez-Gil et al. has shown an expected energy production gain of 14.3%, 33.5% and 37.9% for concentrated photovoltaic cells, 1-axis tracking and 2-axis tracking flat panel PV cells respectively, when compared to a fixed flat PV panel (Gomez-Gil,Wang & Barnett, 2011).

Technology is being upgraded constantly, yet limitations such as cloud cover and weather processes will continue to negatively affect ground based solar collection. In addition, solar tracker integration is essential to determining efficiency of collection at high altitudes for multiple collection strategies. Designs have been proposed for the use of solar arrays stationed in orbit, but the distance from the surface is too great to efficiently transfer the energy. A high altitude solar panel station could be a solution that overcomes the cloud limitation while making energy transfer possible. Since extensive experimentation of collection efficiency of photovoltaic cells at high altitudes, or low temperatures has not been done, HATS 2.0 tracking solar survey will be a great opportunity to expand the science of solar cells, and help to determine the feasibility and practicality of high altitude or space solar energy collection.

As the solar radiation passes from space to the earth, it is weakened in magnitude by the atmosphere in two main ways. The first weakening process is scattering, which includes Rayleigh scattering (atmospheric particles) and Mie scattering (large atmospheric particles). The second is absorption, where the energy from the photons is transferred into heat (thermal energy). The combination of these two processes is called "extinction" (Liou, K. N., 2002, An Introduction to Atmospheric Radiation, 2nd ed., Elsevier Science, New York). With the present composition of the earth's atmosphere being what it is, most of the extinction comes from scattering. The total radiation that falls on the earth's surface can be broken up into two main categories: direct and diffuse. The radiation that comes from diffusion increases as it becomes closer to the surface of the earth; which means it is greatest on the ground. The process of extinction also increases as you get closer to the ground and is strongest in areas where cloud coverage is high like northern European latitudes (redi et al , 2010).

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2. RESEARCH OBJECTIVES

The main scientific objectives of HATS 2.0 were as listed:

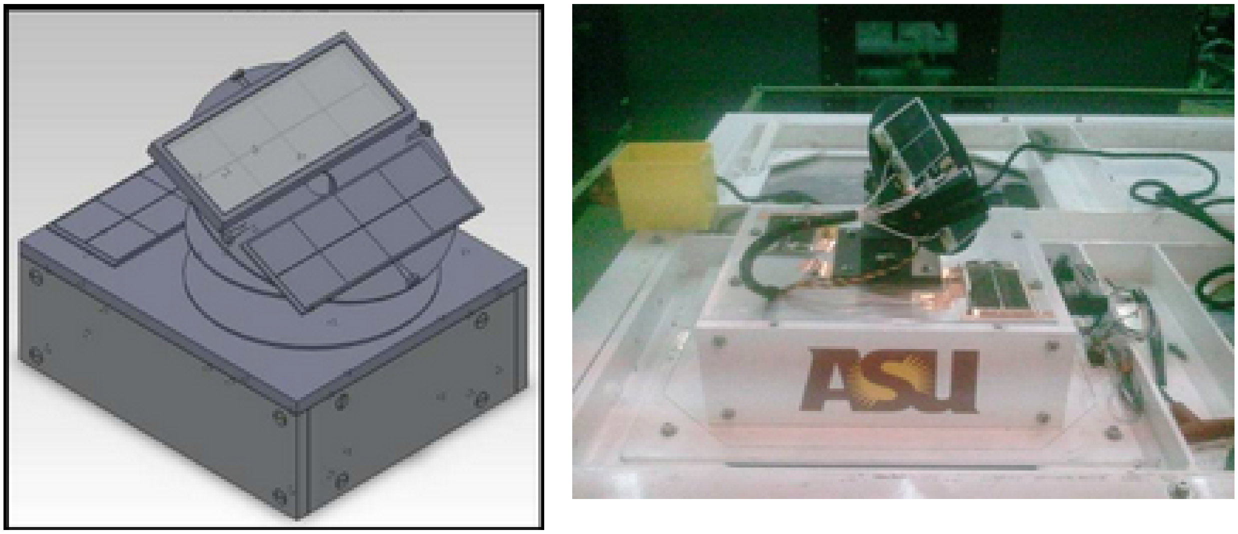
- Quantify the differences in efficiency between each method at high altitude.
- Compare the data to validate theoretical models for the devices by comparing the results with predictions calculated in advance.
- Determine if any of the enhancements are viable for use in cheap space payloads like CubeSat.

Based on previous research performed by Gill & Barnett (2011) it is predicted that the two axis tracker would add a 35% increase in energy gain compared to the standard flat mounted on the payload. It is also predicted from previous research that there would be an increase in energy from the high altitude as well. Less atmospheric gas will is expected to reduce the scattering of solar radiation and, more importantly, provide fewer opportunities for it to be absorbed by other objects and transferred to heat. Avoiding cloud cover will provide the opportunity to increase energy output by as much as 600% over equivalent ground based solar arrays. (Aglietti et. al. 2008). HATS 2.0 expected to have results showing these variable conditions to validate or question claims made in previous researches.

3. PAYLOAD CONCEPT

The High Altitude Tracking Solar Survey (HATS 2.0) was proposed as a solar collection survey for the purpose of collecting data and comparing it to current theoretical models pertaining to high altitude solar output. Future work will ideally involve upgrades to more efficient solar panels as well as concentrators and other sun tracking methods. The design that ultimately flew on HASP 2013 flight included two standard flat photovoltaic panels mounted on top of the payload and two standard flat photovoltaic panels mounted on a one-axis solar tracker. Data such as temperature, pressure, gyroscope, and altitude was collected during the duration of the flight, as well as current and voltage.

The electronics housing structure of the payload was descoped from a wind-turbine experiment, HATS 1.0 flight, and re-flown as HATS 2.0. The solar tracking system proposed was made to satisfy technical requirements that are specific to the studied application of maximizing solar efficiency for comparative analysis. The design of this system aimed to maximize solar energy input through optimal condition such as unobstructed path of sunlight. The system is designed to perform under wind, rain, and temperature variation and remain cost efficient and viable relative to other method of solar collection.



a. Solid Model

b. As built

Figure 1: Solid model and built HATS 2.0

As shown above, Figure a., the payload concept was designed in SolidWorks based on the scarecrow structure of HATS 1. The individual parameters were optimized for space and operational efficiency. Figure b. shows the realization of this design as it was being finalized for integration at the Columbia Scientific Balloon Facility. An onboard arduino in the electronic housing allowed data collection and relay during accent, cruise, and descent. The HATS 2.0 payload was flow on the 2013 NASA High Altitude Student Platform (HASP) in September of 2013. HASP floats to an altitude of 38 km using a specialized high altitude balloon.

4. PRINCIPLE OF OPERATION

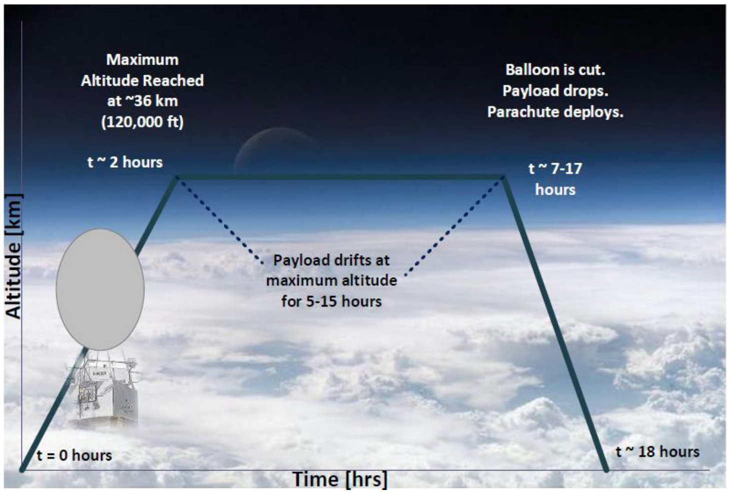


Figure 2: Concept of operations flight plan

The system was initiated at launch and data was logged for the entire duration of the ascent, cruise, and descent phases of the flight. The goals for flight are as follows.

During Ascent & Descent:

- Establish communication with system.
- Monitor temperature to confirm optimal system health and performance
- Collect solar data

During Cruising:

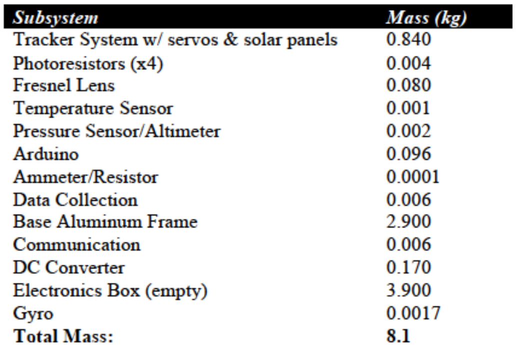
- Monitor temperature downlink to confirm optimal system health and performance
- Collect solar data
- Downlink temperature, solar, and pressure data

5. DESIGN CONSIDERATIONS

The HATS system was designed in accordance with all mass, size, and power requirements according to HASP/NASA protocol.

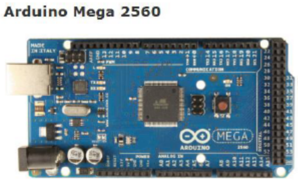
System components not included in the insulating box such as the solar panels, servo, and photoresistors were tested to operate in the full flux of the exterior temperatures. HATS 2.0 system went through cold tests in order to ensure that the system could maintain functionality throughout the temperature flux exposed. A thermal vacuum was initially scheduled to test and analyze the heat dissipation at low pressure and temperatures. Due to the thermal vacuum chamber being unable to be used by HATS, there was no Thermal Vacuum test done until the HASP integration.

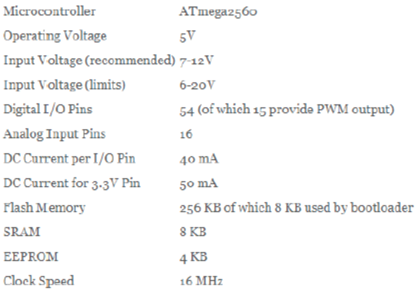
HATS 2.0 has a two axis tracking system that can rotate 180° in the x-axis and 120 ° in the y-axis. The tracking system moved according to the light received from the photoresistors, which was evident during most of the streaming flight that was clear enough to see.



Subsystem	*Mass (kg)*
Tracker System w/ servos & solar panels	0.840
Photoresistors (x4)	0.004
Fresnel Lens	0.080
Temperature Sensor	0.001
Pressure Sensor/Altimeter	0.002
Arduino	0.096
Ammeter/Resistor	0.0001
Data Collection	0.006
Base Aluminum Frame	2.900
Communication	0.006
DC Converter	0.170
Electronics Box (empty)	3.900
Gyro	0.0017
Total Mass:	**8.1**

Figure 3: Most of the mass of the HATS 2.0 payload stems from the electronic box and the base aluminum frame.





Microcontroller	ATmega2560
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	54 (of which 15 provide PWM output)
Analog Input Pins	16
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	256 KB of which 8 KB used by bootloader
SRAM	8 KB
EEPROM	4 KB
Clock Speed	16 MHz

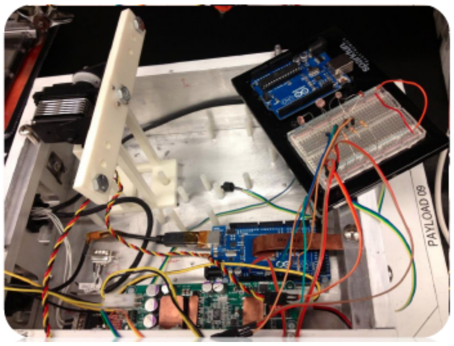
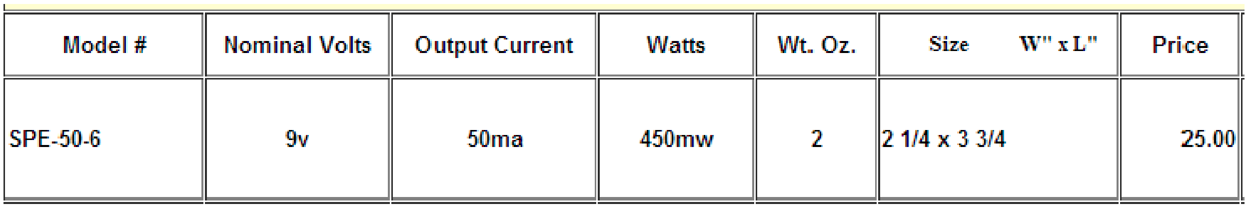


Figure 4: The electronics of HATS 2.0

The Arduino Mega was used to regulate the motion of the solar trackers through the analog input data of twelve photoresistors and two 180 degree metal gear one axis servo. Data input received from the photoresistors on the highest light intensity was relayed through the Arduino to move the servo, rotating the platform to the photoresistor location of highest light intensity. The data output from the solar panels was relayed through a current and voltage sensor, then to the Arduino to log voltage and current to measure power. Temperature, pressure, and gyroscope data will be logged for the post flight analysis. The temperature sensor was also proposed for the purpose regulating the thermal conditions of the payload to mitigate overheating risks. After sifting through data, it seems as though the temperature sensor was always malfunctioning.



Model #	Nominal Volts	Output Current	Watts	Wt. Oz.	Size W" x L"	Price
SPE-50-6	9v	50ma	450mw	2	2 1/4 x 3 3/4	25.00

Figure 5: The specs for all four solar panels on HATS 2.0

6. FLIGHT DATA ANALYSIS

Data from the previous HATS team was analysed and considered throughout the failure analysis portion of HATS 2.0 project. The following temperature graph was used to predict the temperature trends during the 2013 flight. HATS 2.0 did not successfully collect temperature data, possibly due to malfunctioning sensors.

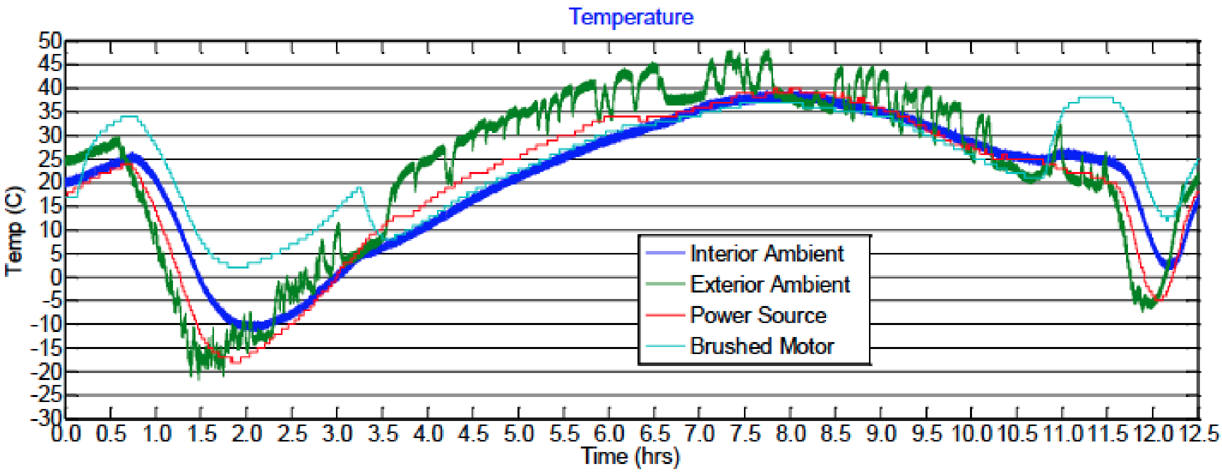


Figure 6: HATS 1.0 temperature data

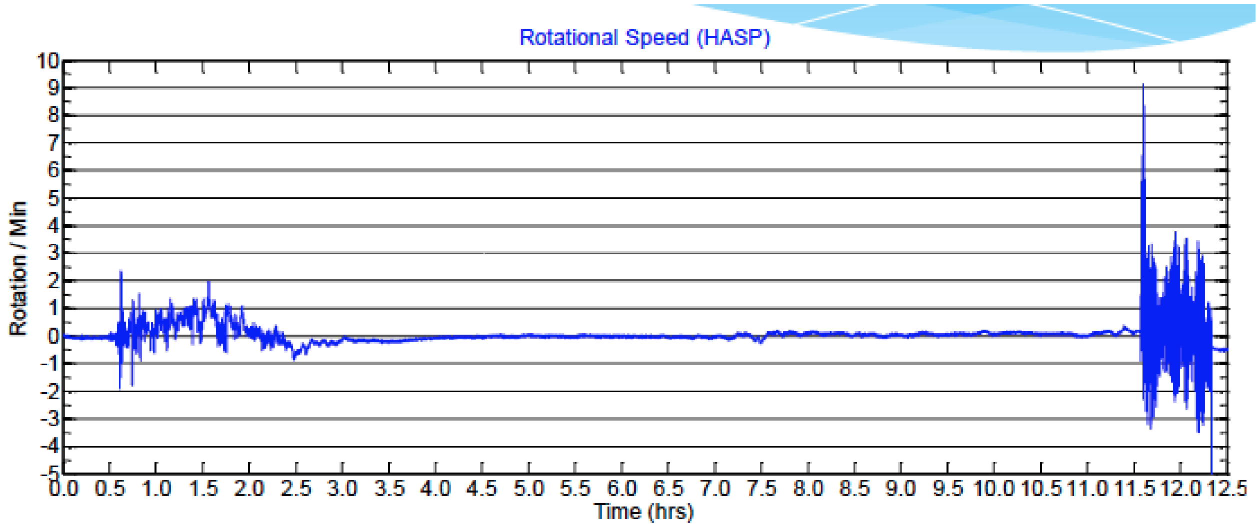


Figure 7: Relative stability in higher altitudes was predicted to be sufficient for the single axis 360˚ servo to track the sun accurately and efficiently.

Based on previous research, team expects higher energy production at higher altitudes. The theoretical models that the team anticipated to compare data to before descoping the fresnel lense, all include a solar output concentrator, like the lense to be incorporated. Therefore the theoretical models are not appropriate for HATS 2.0 data to be compared to at this time. Previous research suggests a 35% increase in output using solar tracking, which is the science point that HATS 2.0 chose to address (Gomez-Gil, F).

Temperature, Current, and voltage data for each type of solar panel, standard flat mounted and standard tracking mounted were recorded every 7 seconds as an output line, within a file made every 7 minutes.

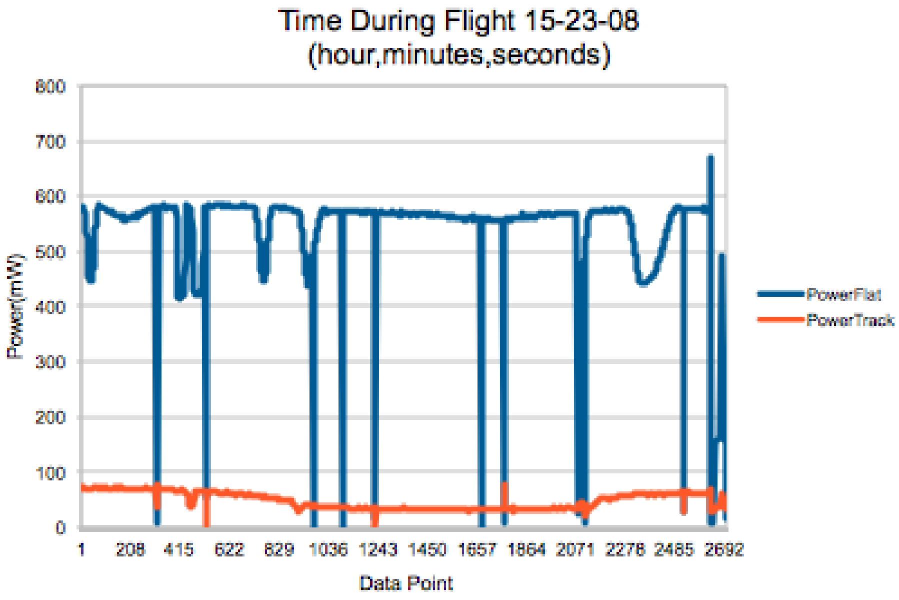


Figure 9: This graph shows plotted power vs. time over a 7 minute period of data collection. Power was calculated, showing dips in both sensors at same times, indicating the sensors working properly.The tracker's power is low due to one solar panel mounted on the tracker malfunctioning.

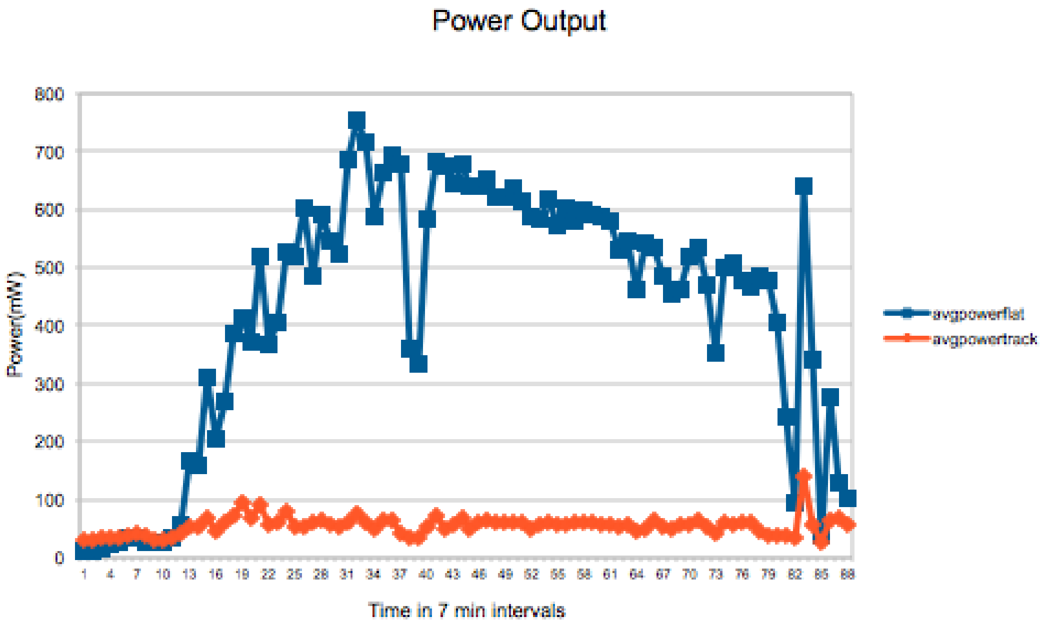


Figure 10: This graph shows the calculated average for power (for the flat vs. tracking solar panels) for the duration of the HASP flight.

This graph shows shows a linear pattern for the tracker, showing the tracker is just as efficient at all times. The output power for the tracker solar panels is very low due to one of the mounted panels malfunctioning. Also shown is indication of weather due to the parabola pattern from flat mounted panel. Figures 9 & 10 show that the panels were most efficient when the sun was overhead. The shape of the power as a parabola as proxy of the sun moving across the sky, which means more power when the sun is overhead and sun angle = 90 degrees. After calculating and analyzing data, the efficiency for the standard flat photovoltaic cell was a higher percentage on average, which could be attributed to the one malfunctioning solar cell on the tracker, or too many shadows casted on the tracker vs. flat cell.

7. FAILURE ANALYSIS

The flight data was indicative of several notable instrument failures resulting in erroneous data and loss of measurements. The data from the second Thermal-Vacuum test, previous to flight, indicates that one of the solar panels attached to the two-axis tracking system degassed and was not properly working for the HASP flight. Data analysis shows the tracking system was working efficiently.

8. FUTURE WORK

Future research would entail additional solar collection surveys at high altitude, with the quality and efficiency of solar panels varying. In the initial design of HATS 2.0, a solar concentrator lense as well as additional tracking methods were considered but ultimately de-scoped. Additional research into designing a larger solar array with multiple fresnel lenses would be beneficial to compare with current theoretical models. Additional analysis on the thermal vacuum test data could yield more insight as to what moment one of the solar panels on the tracker degassed.

9. TEAM MEMBERS

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