HASP 2012 Flight: Payload 10 Result Analysis

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Payload Class: Large **Flight Number**: 2012 **Payload ID:** 10

The High Altitude Student Platform (HASP) 2012 Launch occurred on September 1, 2012 at approximately 8:20 am MST. As one of twelve student payloads mounted to the platform, the "HELIOS" Payload 10 was successfully integrated, launched, and recovered by the joint efforts of the NASA Columbia Scientific Balloon Facility (CSBF) and the Louisiana State University HASP program team. The primary objectives of HELIOS included analyzing the Sun in Calcium (II)-Potassium and Hydrogen-Alpha wavelengths at an approximate float altitude of 120,000 ft. The payload successfully operated for roughly thirty minutes and collected over 1000 pictures, four of which directly captured the sun.

I. Mission Overview

Team HELIOS attempted to design and construct a payload that utilizes an Attitude Determination and Control System and SHACK (Solar Hydrogen-Alpha Calcium Potassium) telescope imaging system to collect high-resolution images of the Sun throughout flight. Our primary mission objectives included:

- To observe and analyze solar phenomena with the SHACK imaging system
- To characterize the motion of the HASP platform
- To develop an ADCS capable of
  - Tracking the motion of the Sun through the sky
  - Counteracting changes in the motion of the balloon
  - Orienting the SHACK towards the Sun throughout float
- To verify the accuracy of the ADCS with the images collected
- To determine the feasibility of high-altitude balloon observatories

Over the course of the design and assembly of HELIOS, several of these objectives were reevaluated. The most significant alteration was in the design of the ADCS system. Rather than actively tracking the Sun, it passively scanned the field of view as discussed further in Section II Design Overview.

A. Theory of Concepts

Observations of the Sun currently rely on ground and orbiting solar observatories. Though these observatories have provided high quality scientific data, they are hindered by certain factors. The main factors are cost, accessibility, and atmospheric interference. Ground based observatories, such as Mauna Loa Solar Observatory and Big Bear Solar Observatory, are affected by atmospheric interference, while orbiting observatories are greatly hindered by cost and accessibility.

- James Webb Telescope cost: $1.6 billion
- Kepler Telescope cost: $600 million
- Average Shuttle Launch cost: $450 million

This mission offers potential analysis of:

- Lower Chromosphere (Ca(II)-K)
- Middle Chromosphere (H-Alpha)
- Solar Magnetic Field (Ca(II)-K & H-A)
- MicroFlares (Ca(II)-K & H-A)
- Arch Filaments (Ca(II)-K & H-A)

The HELIOS mission offers an alternative design to current observatories. Ultimately the HELIOS system could be expanded to not only solar imaging but also to a broader range of optical systems.

II. Design Evolution

A. Structure

The structure was responsible for maintaining the physical integrity of the HELIOS payload through ascent, descent, and landing. Throughout the progress of the HELIOS payload, the original structure design evolved to accommodate subsystem design changes, and general manufacturing capabilities.

Proposal Design:

- 3 Segment Structure 1/4’’ Al Plates
- Seg. 1: 30x38x20 cm Houses Computing/Data Storage System, electronics, & Power Board
- Seg. 2: 30x38x10 cm Houses wiring& motor components for ADCS and SHAIRC System

Figure 1: Proposal Structural Design

- Seg. 3: SHAIRC System mounted on ADCS gear System

Revised Design:

- Maintained Segment Concept Design from Proposal
- Al T6-6061
- Improved truss design
- Thermal Radiative Plate
- Three Segment Design still in place
- 30cm X 28cm

Pre-Post Flight Design:

- ADCS Steel Chain Drive Rotary Table
- Final Double Barrel SHACK mounted on ADCS chain drive
- Weight Mitigated through additional trusses on all panels
- Removed thermal Radiative Plate

B. Attitude Determination and Control System

The Attitude Determination and Control System is responsible orienting the imaging system toward the Sun. Initially the ADC system was designed to actively track the position of the Sun as well as orienting the SHACK system toward the Sun. The most significant change from the initial design concepts to the final flight-ready design occurred in the ADC system.

The main change occurred in the scale down of the active control system. Rather than actively tracking the Sun during flight, it instead passively scans the entire field of view. Beginning at 0˚ elevation, the payload rotates 4˚ counter-clockwise in the azimuth, takes a picture, and then rotates another 4˚, repeating until the telescopes have spun a full 360˚ in azimuth. The SHACK then increases elevation by 3˚, and proceeds to spin 360˚ in the clockwise direction. The process repeats until the payload has scanned the full 360˚ azimuth and 50˚ in elevation field of view, taking a total of 1800 pictures during this time.

Due to the design of the wire harness in the electronics housing below, it was necessary to alternate spin direction after each full rotation to avoid “over-twisting” of wires. Additionally, the maximum elevation that could be obtained was limited by both the surrounding field of view and the USB cables protruding from the back of each telescope camera.

Proposal Design:

- Design Inspired by SPARTAN-V
- Turntable design to rotate telescope system
- Pitch arms attached to rotary table, hold & pitch SHACK

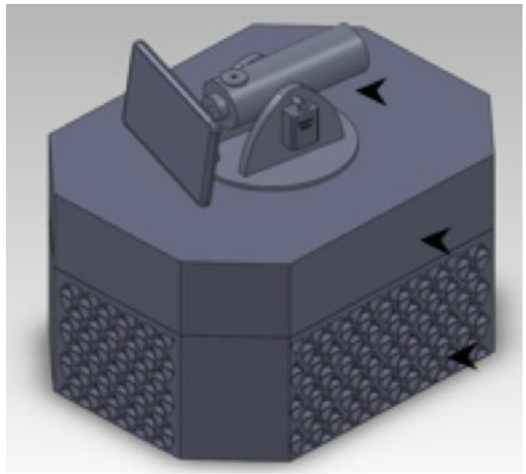

Figure 4: Revised Structural Design

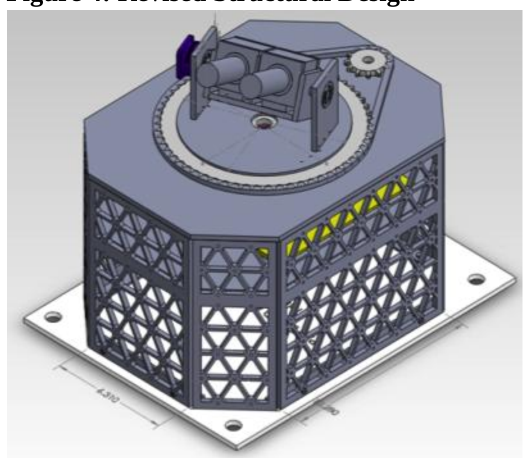

Figure 4: CDR Level Pre-Flight Design

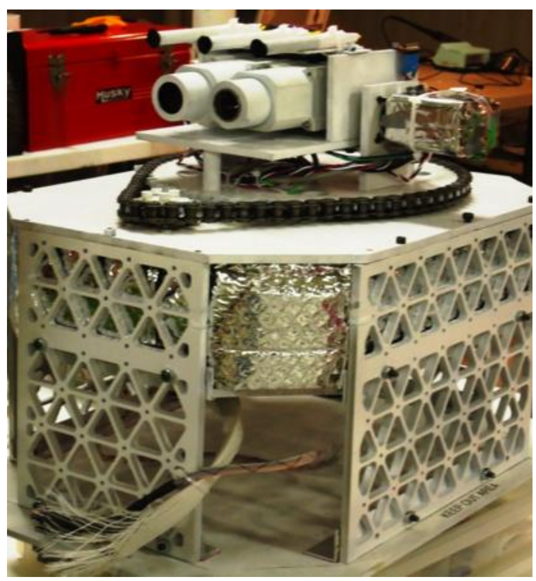

Figure 4: Flight Design

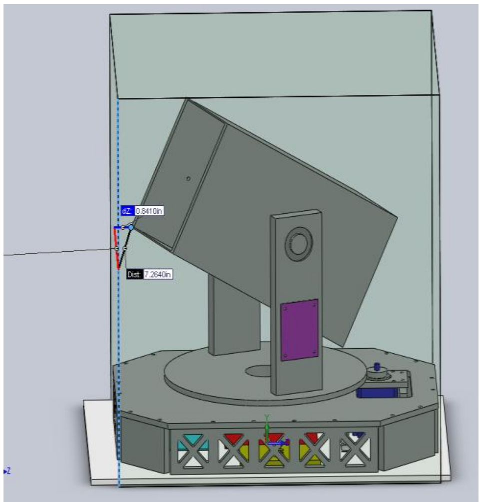

Figure 7: ADCS Proposal Design, Based on SPARTAN-V Payload

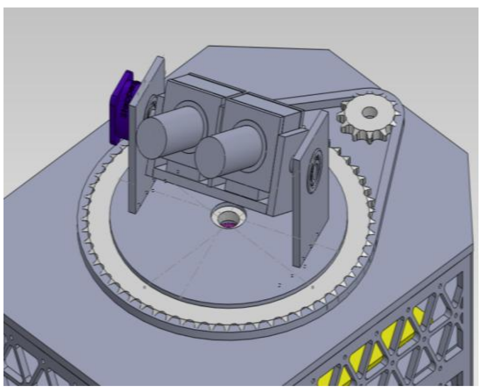

Figure 7: ADCS CDR Level Design

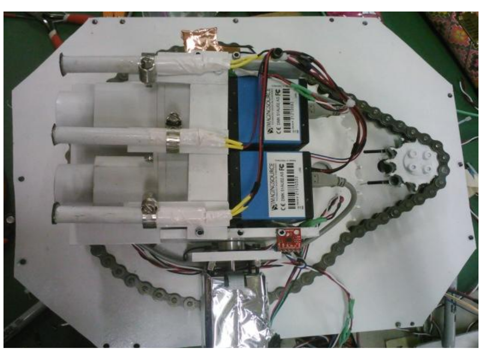

Figure 7: ADCS Flight Module

- Two stepper motors for each respective direction (pitch & yaw)
- Photodiode array (8-12) arranged around rotary table (yaw Solar Tracking)
- Photodiode array arrange (4) on aperture of telescope (pitch Solar Tracking)
- Sensors: 2 Accelerometers, 1 magnetometer, and gyroscope
- Secondary Solar tracking Design: Image processing
- Active Control Loop and Feedback Loop

Pre-Flight Design:

- Steel Alloy Chain Drive
- Sprocket Ratio of 5 to 1
- With Stepper Motor, .18deg/step provided
- Automatic control system (Pitch 3 Degrees per full rotation)

C. Science System

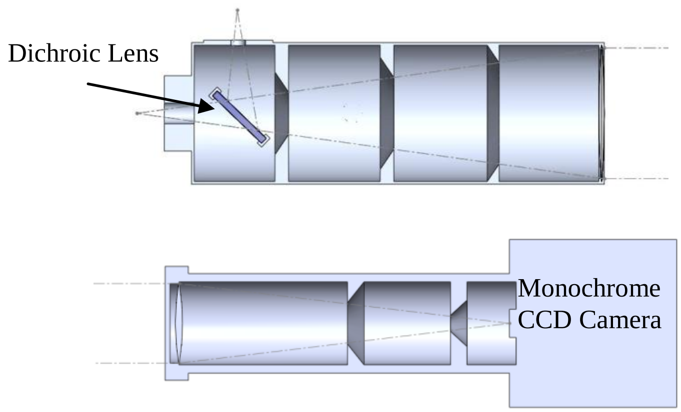

Figure 8: SHACK Single Barrel Proposal Design, depicting Internal Baffling

The SCHACK system is designed to be able to capture images that are useful to the ADCS and can also be used for scientific analysis post-flight. Therefore, the field of view of the system must have enough allowance for the ADCS to track the sun without requiring it to be incredibly precise. Since the sun occupies a .5x.5 degree portion of the sky, we set our field of view to be 4x3 degrees in order to provide a sizable margin for the control system.

There were two significant changes in the scientific design throughout the design processing. The initial change was the addition of two telescope barrels as to one telescope barrel. This allowed for the opportunity of using two separate filter systems per wavelength as well as increase resolution quality by removing a dichroic lens from the design. The second main change was the removal of the Infrared imaging and addition of the Calcium II Potassium imaging due to various reasons:

- Increase in resolution
- Software Interface
- Ease of Manufacturing
- Cost

1. *Proposal Design:*
   - Single Barrel Design
   - Dichroic Filter to split incoming light to two perpendicular positions for each wavelength
   - Filming via a monochrome camera

- Imaging two wavelength, Infrared and Hydrogen Alpha
- Baffle the interior of the barrel

2. *Revised Design:*

- Two Barrel design for each wavelength
- Internal Baffles changed due to 2-barrel design

3. *Pre-Post Flight Design:*

- Two Barrel Design
- Imaging CaII K and H-alpha
- Neutral Density Filters
- DMK 51AU02 Monochrome CCD Camera
- Reflective Narrow Bandpass Filters
- Baffled Barrel, matte Krylon Black
- Mounted onto ADCS

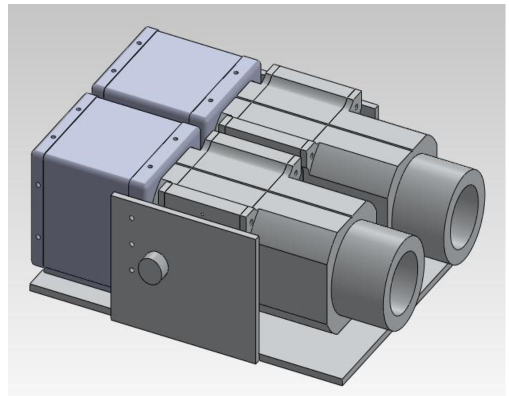

Figure 10: CDR Level Science Design

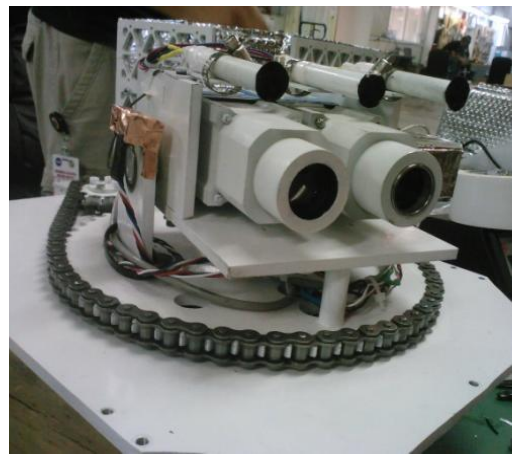

Figure 10: Science Flight Telescopes

D. Power and Computing Systems

Power Electronics:

Conceptually, the payload has a very simple power system. 30V electricity was supplied from HASP and that power was then converted primarily to two different levels, 5V and 9V. The 5V power was supplied to the computer, and the 9V power was supplied to the motors and motor drivers. Other components then would convert the power to the other required levels.

1. *Proposal Design:*

Initially, there were more components that each had separate power rails. Each motor driver, each microcontroller, the sensors, and the computer had separate regulators. While it certainly worked, it was unnecessary to have so much separation of systems.

This separation of systems also caused issues with the initial startup of the payload. These multiple parallel circuits for power regulation created a fairly large capacitive load. This caused no problem after the payload had been powered on and allowed to reach steady state, but the extremely large capacitance on the input to the regulation circuitry caused large transient current spikes when power was first applied. Upon attempting integration in Palestine, TX it was found that these transient spikes would cause problems with the HASP power system, and that a smaller response was needed otherwise fuses would be blown.

2. *Pre-Flight Design:*

Primary design developments included:

- Microcontroller consolidation
- Usage of a development board
- Changing voltage levels of motor regulators
- Prolonged power up sequence

The decision was made to consolidate many of these parts to form a smaller, simpler, power system design. The computer was given a higher wattage converter, the two microcontrollers were consolidated into one, and the extra 3.3V rail was removed. Also, the motor regulators were consolidated to one part and were redesigned to supply power at a higher voltage. This was to help fix a torque issue with the attitude control subsystem.

Initially, there were two microcontrollers. One would interface with all of the sensors of HELIOS, and one would be used to interface with the motor driver. This was redundant and unnecessary, so the functionality was consolidated onto one microcontroller. We also switched to a development board that had onboard 3.3V and 5V regulators and a USB connection. This meant that power could be given to the microcontroller through the USB connection, and that the additional 3.3v regulator for the sensors could be removed, since one existed on the development board already.

The stepper motors were used to control the pitch and yaw of the imaging system. The motors were initially powered at a 5.8V and were current limited to not exceed 2.1 amps per motor. According to our initial design, this would supply enough torque to actuate the motors at ½ step micro-steps. Upon actual construction of the payload, the motors struggled to turn in certain ranges of motion. There was not enough margin in the design of the motor system, and the torque was insufficient. Thus, to increase the torque without overly changing the associated circuitry, the power being given to the motor drivers was increased to 9V.

Consolidating the circuitry helped with the issue of the transient power spikes; to ensure that there were absolutely no transients, some control was added to the power regulators. When power was first applied, the computer turned on, followed by the hard drive and cameras, then the microcontrollers, and finally the motors one at a time. This prevented any transient power spikes and prevented fuses from being blown as soon as power was applied.

3. *Further Improvements:*
Several system flaws could be mitigated, should further consideration be paid to the following:

- Thermal mitigation
- Power sense circuitry
- Component power control

There were a few fundamental issues that could be resolved to create a more robust power system. The payload's most common issue involved excess heat generation. Due to thermal and electrical inefficiencies, electronics tend to emit significant heat. The parts were chosen more on price and power specifications than thermal properties. This was convenient for ground testing, but it later was found that the parts would get too hot for reliable operation when in more extreme conditions. For example, the part that regulated power to the motor drivers shorted its excess heat to the printed circuit board. When cooled by convection, this causes no problem, but the thermal extremes of space made the regulators prone to operating beyond the thermal bounds specified in their operating rangers. In retrospect, the consolidation of two motor regulators onto one was a poor decision. It likely led to thermal issues, which may have caused it to fail and may have caused the Payload 10 fuse to be blown.

Furthermore, there was no sensing circuitry in the power system of HELIOS. The power distribution board simply supplied power to the different subsystems. However, having knowledge of current and voltage usage of each of the components would be extremely helpful. A next iteration would have sensors to detect the voltage and current applied to each subsystem.

Along with knowledge of the state of the power systems, more refined control of the power systems would be helpful. The only fully controllable power states were the states of the motor drivers. The other regulators were turned on one at a time by taking advantage of the startup sequence of the computer and clever placement of pull down resistors. However, computer control of the power supplies could help both with power control and thermal control. With control over individual regulators, certain components could be powered off and allowed to cool, without having to turn off the entire system. Similarly, removing many of the fuses and replacing them with PTC resettable fuses coupled with computer controller power states could allow for recovery from power failures.

E. Sensors and Embedded Electronics

The embedded electronics can be divided up into three categories: data inputs, data outputs, and interfaces between the two. Very little data processing was done onboard the HELIOS payload, and thus data would simply flow from data input, to interfaces, to a data output. The data inputs consisted of the cameras, temperature sensors, compass, accelerometer, and photodiodes. The information from these sensors was sent to the microcontrollers or computer. These interface devices would then forward that data to the solid-state disk, serial downlink, or motor drivers.

4. Proposal Design:

The initial embedded electronics design consisted of two microcontrollers and a computer. These three devices did all of the computation and acted as interfaces between all the other peripherals. One microcontroller was interfaced to all the sensors, and the other was interfaced to the two motor drivers. The computer interfaced to the two microcontrollers, the two cameras, and then also acted as the serial downlink/uplink manager and data storage manager. This information would then be stored on the SSD, written to the serial downlink, or used to actuate the motors.

The temperature sensors were linear, analog, temperature sensors. To accommodate all of the sensors on one microcontroller, they were multiplexed down to two input pins. The compass and the accelerometer were connected to the microcontroller using the I^2C protocol. The photodiodes also produced an analog voltage that had to be measured by the microcontroller. None of these can be interfaced directly to the computer, which was why the microcontroller was needed. The microcontroller was connected to a RS-232 level shifter, which then connected to a serial port on the computer.

Likewise, the second microcontroller was connected to the computer by a RS-232 level shifter. This microcontroller then was connected to two motor drivers. By changing the state on the pins on the motor driver, different micro stepping and power configurations could be selected. When the motor driver receives a rising edge triggered pulse from 0v to 3.3v, then the motor would turn one (micro) step.

Finally, the cameras and solid state disk were connected to the computer via USB.

5. Revised/Post Flight Design:

The most significant change that was made between the final and initial design was to combine the functionality of the two microcontrollers. A development board was purchased to allow for easier testing and prototyping. For the final design, a custom PCB was designed to interface to this development board, and the board was used for flight. In addition, digital thermal sensors replaced the analog sensors in the first design. These sensors all used a common bus and one pin on the microcontroller, so the multiplexer for the temperature sensors also was removed. This led to designing one PCB for all of the sensors and microelectronics. There also was an issue with connecting two cameras to the computer through an external USB hub. To fix this issue, an extra USB port was added to the computer by using several of the pins on the PandaBoard expansion connector. Beyond that, all of the remaining changes with these electronics systems were made in software.

6. Future Improvements:

There were very few problems with the sensors and microelectronics. They were consistently the most reliable component of the electronics subsystem. The most significant potential changes would be to the hardware interface to the sensors. Simple pin headers were used for most of the connections to the sensors and motor drivers. These certainly worked well most of the time, but when doing work on the payload, it was found to be easy to accidentally disconnect the wires since there was no lock on the connectors.

The motivation for having separate microcontrollers for the attitude control system and the attitude determination system was twofold. It allowed for separation of systems and for multiple people to work on different parts of the subsystem independently. It also allowed all of the circuitry for actuation on the motors to be placed on a different circuit board than the circuitry for the sensors. In the initial design, where the electronics to actuate the motors were placed on the rotary table, then it was necessary to separate the systems to minimize the number of wires running between the lower and upper electronics bay. This requirement for separate microcontrollers was found to be redundant, but later designs might want to take advantage of the extra power and space provided by two microcontrollers. In later designs, if extra functionality were needed - such as power sensors - then multiple microcontrollers would be preferable.

F. Thermal System

1. Proposal Design:

In the initial design process the HELIOS team requested to be provided the opportunity to utilize an Aluminum Integration Plate to provide higher release of excess thermal energy to the HASP Bus. The addition was to improve conduction of heat from the processor units and other heat-producing mechanisms away from temperature sensitive components, reducing the likelihood of overheat and system failure.

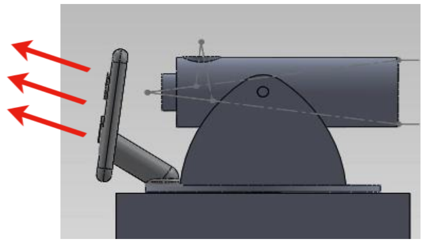

Figure 12: Revised Thermal Design with Radiative Plate

2. Revised Design:

A thermal plate that was designed to radiate 35 W was our main secondary change since the payload was calculated to produce 75W at max. To ensure that every piece of the payload was able to radiate as much heat as possible, the payload was designed to be white for higher emissivity. All heat producing electrical components were to be thermally strapped/shorted.

3. Pre-Post Flight Design:

The radiative plate and aluminum mounting plate idea were removed from the design. Excess thermal energy was mitigated through a series of thermal shorts that were attached to individual components with thermal conductive epoxy and Kapton tape. Each heat-emitting component had a One-Wire temperature sensors attached, resulting in 3 external sensors and 8 internal sensors.

Figure 12: One-Wire Temperature Sensor Used In-Flight

III. Payload Performance

G. Integration and Launch

The HASP platform offers several opportunities for full integration, a process that requires several criteria are met: first payload power consumption is below 75 Watts at a constant voltage of 30 V and a current draw of less than 2.5 A (including transience), and successful communication necessary to payload function, including uplink of commands and downlink of data.

HELIOS attempted to integrate to the HASP platform on multiple occasions. The first two attempts to integrate were complicated by power issues caused by an incorrectly wired EDAC power connector. One power and one ground pin were mistakenly reversed during assembly, causing over-currenting and multiple fuses to blow in both the payload and HASP platform before the problem was rectified. During both attempts, the payload maintained fully functional communication and command uplink. HELIOS successfully integrated (meeting all power and communication requirements) four days prior to launch.

The payload launched and reached float altitude fully intact. No power was supplied to the payload during launch or ascent to float altitude and HELIOS collected no data during this time.

H. Float

For the duration of its operation at the 120,000 ft float altitude, HELIOS was largely successful. As described in Table 1, the payload operated for approximately 30 minutes before the HASP Payload 10 fuse was blown at 11:19 AM MST. Unfortunately, there was no indication of any system failure in the status packets downlinked by the on-board computer, and so the exact cause of failure remains unknown. It is suspected that, due to thermal issues, several power components began operating abnormally allowing for transience in the system.

The power "spikes" and "drops" referenced in Table 1 are data points from the HASP Log Files during flight for Payload 10 voltage and current readings. While the power readings are far beyond the normal bounds of operation (nearly 7000 W at some points), they seem to be anomalies in the data collection. They are included to note interesting data behavior, not as a cause of system failure. Despite a blown fuse and post-fuse voltage and current sensing, the payload 10 sensors would occasionally sense voltage and current draw post-failure.

Table 1: Timeline of Payload Events

Local Time (MST)	Event	Comments
8:19:00 AM	Launch	Clean launch, clear weather conditions
8:20:00 AM	Ascent	Approximately 2 hour ascent to ~120,000 ft
10:44 AM	Power-On	Power-on command uplinked through HASP
10:45 AM	Computer Booted Power to SSD, Cameras Arduino Initialized Motor Drivers Powered	
10:45:05 AM	Boot Completed All Systems Initialized First Image Taken	
10:49:00 AM	First Health and Status Packet Downlinked	No Errors Evident in Boot Cycle. The computer mounted all USB Devices and recognized both cameras
11:03:11 AM	First Power Drop	V = 5.38 V I = 0.02 A
11:04:40 AM	Second Power Drop	V = 40.55 V I = 0.43 A
11:15:10 AM	Third Power Drop	V = 12.17 V I = 12.17 A
11:15:35 AM	First Power Spike	V = 419.09 V I = 15.53 A
11:15:44 AM	Second Power Spike	V = 172.11 V I = 18.95 A
11:19:05 AM	**Payload Shutdown**	**Cause of failure not indicated in any status packets downlinked during flight.**
11:19:28 AM	Third Power Spike	V = 1.1 V I = 0.47 A
11:21:20 AM	Fourth Power Spike	V = 314.81 V I = 24.25
7:19:00 PM	Approximate Termination	

I. Recovery and Post-Flight Analysis

Upon recovery, several elements of the payload had shifted since integration. Externally, the only notable changes were in the sensors mounted around the SHACK. The photodiodes had dislodged completely and the wires had slipped from their original placement. The structure and telescopes seemed relatively unchanged save for a few scuffs, scratches, and dusty surfaces likely incurred during landing and transportation. Internally, the wires had become very wound and tangled, disconnecting from the Arduino at several points. Most notably, the compass had become completely disconnected and returned no readings throughout flight.

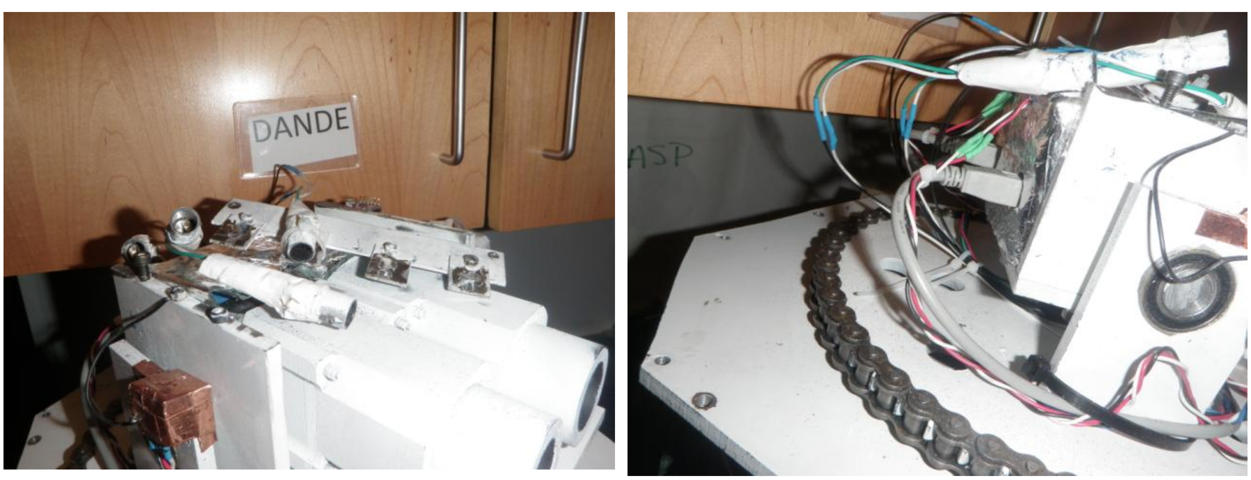

Figure 13: Photodiodes Dislodged from Mounts Upon Recovery

Figure 14: Wires Became Tangled and Disconnected as Platform Rotated

IV. Results

A. Science

1. Telescope Assembly:

The telescope structure incurred no damage internally or externally during flight or landing. The CCD sensors were clear of debris; the cameras and lenses were not damaged. The solar images captured by both the Hydrogen Alpha and Calcium Potassium barrels were not as focused as expected and this can be due to various reasons. One possibility is the fitting of the camera to the barrel over-time (through the testing process) became slightly loose due to repeated tensioning and releasing of the screw threads during calibration. Also, the packing of the optical assembly may have been too tight; while it would allow air to vent, it could have caused the water vapor from lower-altitude to collect and condensate on the lenses.

2. Hydrogen Alpha:

The optics within the hydrogen alpha barrel were tightly fitted between two fitting rings. This provided a small amount of room around the edges of the lens and filters. The fitting of the barrel assembly provided little to no space for gas and/or moisture to leak out of the barrel. In near vacuum, it is possible that moisture from the ground did not escape and that only some of the moisture was evacuated from the parts used to manufacture the telescope and optics (majority of the internal moisture is assumed to have come from Al T6-6061). This moisture was then stored within the barrel and subsequently became frosted to the optics, causing blurring, which is seen in the hydrogen alpha images in Figure 16. These images show that there was a solid orb of light surrounding the Sun.

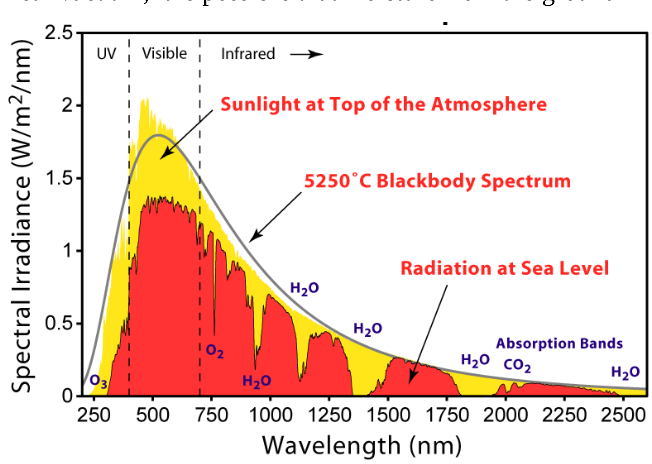

Figure 15: Solar Radiation Spectrum

The hydrogen alpha band of the visible light spectrum is one of the most intense emitted by the Sun. At ground level, with the optical filtering used, we were already maxing out the shutter speed of the camera (1/10,000th second) in order to maintain proper contrast. A slower shutter speed would result in an oversaturated image. Once at float, without any atmosphere to reduce the intensity of the light, the settings used were not adequate enough to produce an image of proper contrast. The solar intensity is approximately

37% greater (at 656nm) above the atmosphere than it is at sea level (~1.85W/m/m/nm vs. 1.35W/m/m/nm) as shown in Figure 15.

3. Calcium Potassium:

At flight operations it was necessary for the Calcium-Potassium barrel to have additional filtering. Unfortunately the additional filter did not arrive on time to be integrated and tested with appropriate timing and hardware. A neutral density filter was added in order to decrease over-saturation of light emitted by the Sun. This caused the optics to become misaligned and provided the image shown in Figure 16. Another issue that occurred with the calcium potassium camera is that after plugging camera into the computer post retrieval, an error was given indicating that the camera was not sending any video. The computer recognized the hardware and software but no data could be received.

4. Image Analysis:

Figure 16: Images from the Hydrogen-Alpha (Left) and Calcium(II)-K (Right) Telescopes During Float

In order to prove that the SHACK systems was appropriate for solar imaging, any images taken by it were to be compared to the images of a ground based solar observatory. Mauna Loa Solar Observatory (MLSO) provided a solar image in the Hydrogen-Alpha wavelength taken the same morning of launch (September 1, 2012) in order to allow the HELIOS team to analyze image correlations. Figure 17 (left) features the reference image provided by MLSO in which the sun is at a resolution of 600-800 pixels across. Figure 17 (right) features the pixel intensity of the MLSO image.

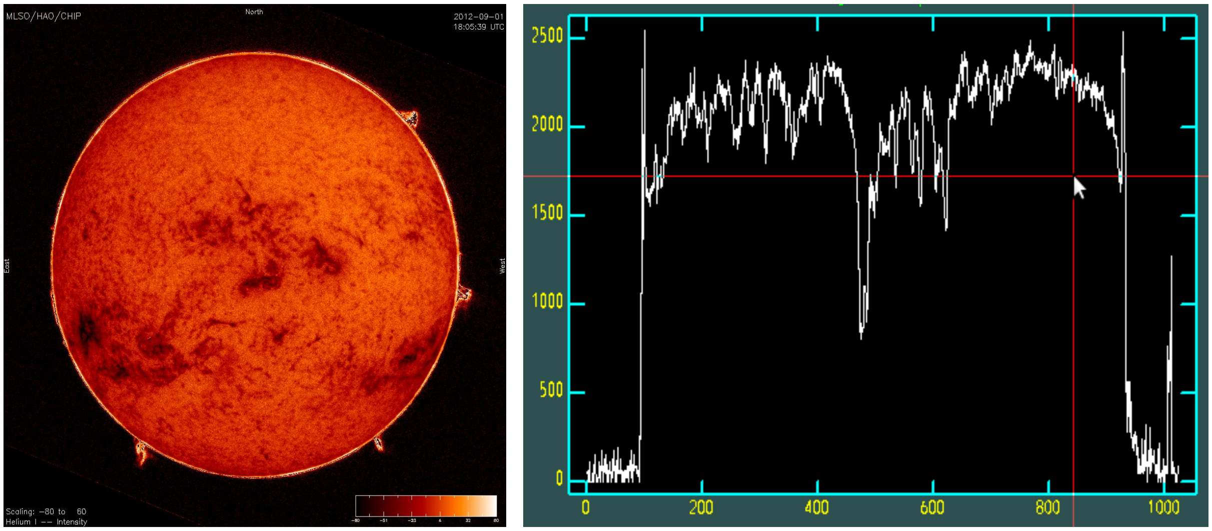

Figure 17: Hydrogen Alpha Solar Image from Mauna Loa 9/1/2012 (Left) and the Plot of Pixel Intensity (Right)

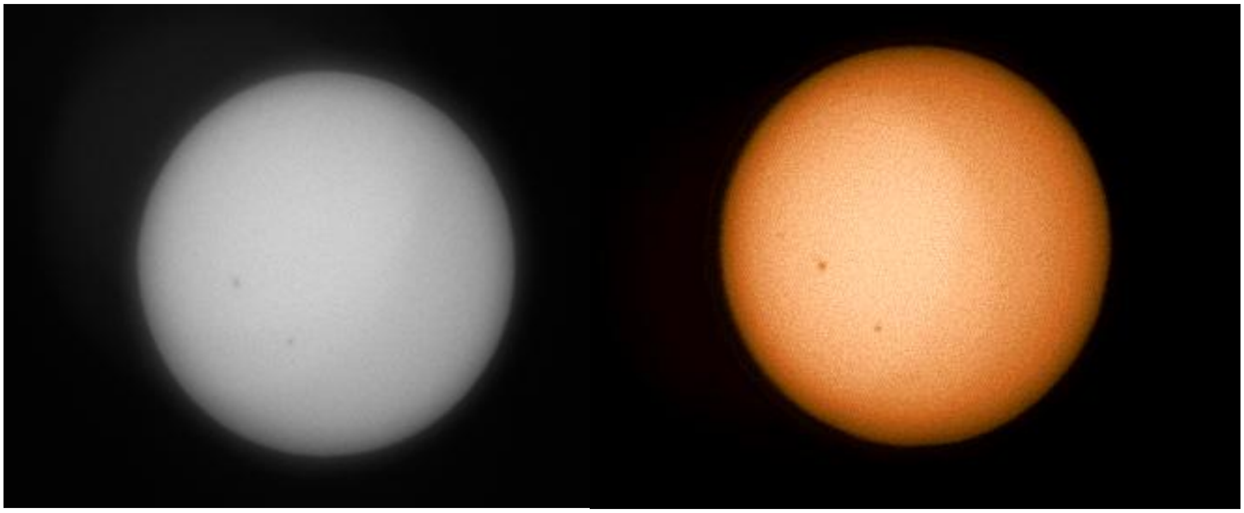

Figure 18: Hydrogen Alpha Solar Image Taken During Ground Testing (left) and recolored (right)

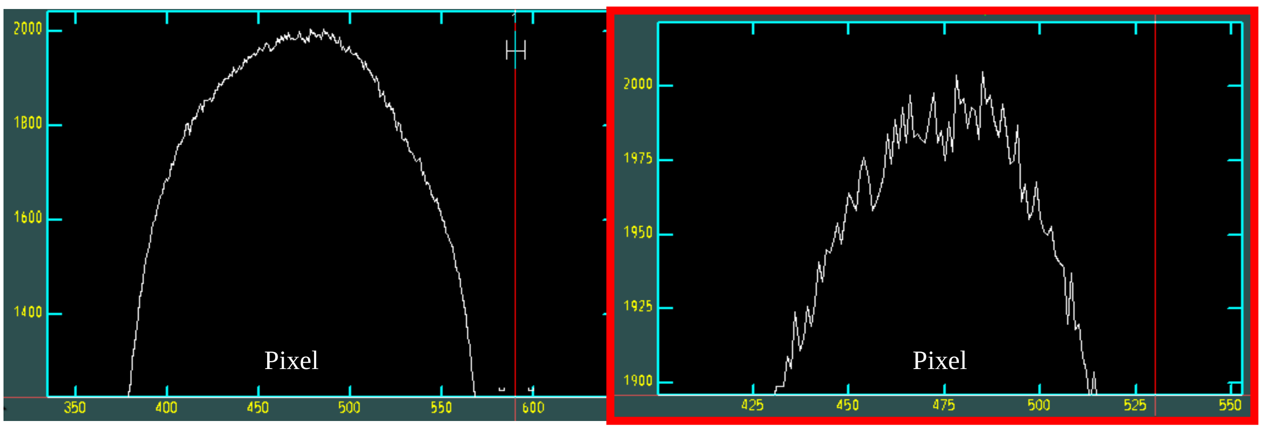

Figure 19: Pixel Intensity graph of Figure 18 (left) zoomed in to show intensity variances at peak (right)

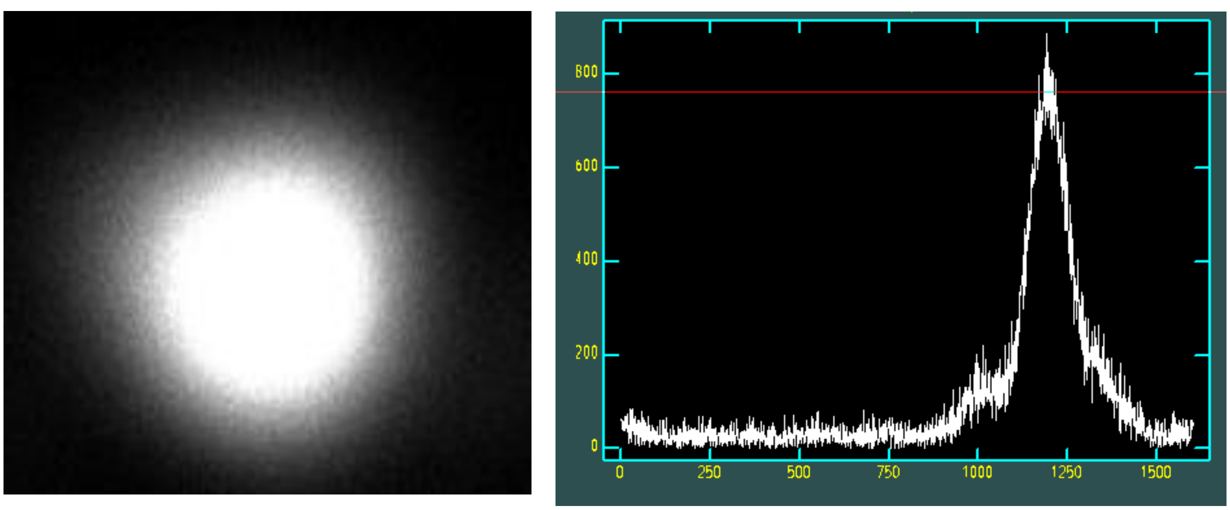

Figure 20: Zoom-in of Figure 16 to show lack of resolution (left) and significant noise in intensity plot (right) relative to Figure 19

The MLSO Image acts as a reference point by which we can compare the quality and features of SHACK images. Considering the 200x200 pixel area of the Sun in Figure 18, the clarity of the ground testing images is very reasonable. Although the image was taken during a time of very low sunspot activity, three sunspots are visible in the recolored image; in a time of greater solar activity, it is possible even a flare or other filament may be observed. The quality of these images could be greatly improved with a zoom lens and stronger neutral density filters, implying the system has the potential to be greatly improved with simple alterations.

Conversely, the flight images (Figure 16 and 20) are significantly blurrier. Only two solar images (one in each wavelength) were captured during the 30-minute operational period, and so no concrete conclusions regarding solar features or image properties can be drawn. The notable quality difference between flight and ground images indicates that flight conditions altered the optics systems. Most likely, the telescopes failed to vent all of the moisture from the interior lenses and filters, resulting in condensation on the optics as discussed earlier.

5. Improvements:

The ground images taken during calibration offer the potential of an imaging system taking clearer images of the Sun at higher altitudes. The HELIOS mission was capable of capturing images of the Sun but the SHACK system must be further improved to capture intricate solar features. The HASP 2013 is proposing to re-fly the SHACK system, allowing failures encountered in the HELIOS science mission to be mitigated. Major improvements should focus on refining filtering, venting the optics system, and further calibration testing.

B. Computing and Electrical System

6. Microcontroller Errors:

The onboard microcontroller provided an interface between the various sensors, the motor driver, and the main computer. It continuously sends sensor readings to the computer. It also waits for commands to drive the motors from the computer. After the flight, there were errors with the microcontroller. It was no longer sending information continuously. However, upon reloading the code, the microcontroller worked without issue.

The program memory of the microcontroller must have been corrupted in order to get a unresponsive, but reprogrammable microcontroller. This issue was likely unrelated to the power issues described above. There are multiple levels of isolation between the main power rails and the power to the microcontroller.

7. Compass disconnect:

The HASP payload had a two-axis accelerometer mounted to the top of the SHACK. This compass was used to provide feedback on the heading angle of the telescope. During the first power on, when HASP was still on the ground, compass data was being successfully downlinked. However, in flight, the accelerometer was no longer providing data. After a post-flight examination of HELIOS, it was seen that the compass was no longer connected.

This was due to an overextension and over twisting of the wires that led from the compass down to the electronics bay. There was no method implemented for keeping track of telescope state between shutdowns. There was no active tracking of the sun, and the SHAIRC was simply searching the sky in segments. This meant that each time the payload was powered off then on, the SHAIRC would start rotating in the same direction, and thus the multiple power cycles before flight led to the over twisting of the wires, which pulled the wires of the accelerometer off of its headers.

8. Power shutoff:

After approximately 30 minutes, power to the HELIOS payload was shut off. The power data from the HASP Log files shows a power spike where the voltage apparently increased to 400V and the current increased to 15 amps. Shortly thereafter, the payload stopped drawing power altogether.

Table 2: Significant Power Events

#	Time	Event	Readings	Notes
1	9/1/2012 8:44:30 AM	Power On	Current: 0.04 Voltage: 30.65	Expected Operation
2	9/1/2012 9:03:11 AM	First Drop During Normal System Operation	Current: 0.02 Voltage: 5.38	Unexpected Operation for a duration of approximately 1 minute
3	9/1/2012 9:04:40 AM	Second Drop During Normal System	Current: 0.43 Voltage: 40.55	Unexpected Operation for a duration of approximately 2 seconds

		Operation		
4	9/1/2012 9:06:06 AM	Max Current Output During Normal System Operations	Current: 1.42 Voltage: 30.27	Expected Operation
5	9/1/2012 9:15:10 AM	Third Drop Suring Normal System Operation	Current: 0.97 Voltage: 12.17	Unexpected Operation for a duration of approximately 1 second
6	9/1/2012 9:15:35 AM	First Spike	Current: 15.53 Voltage: 419.09	Unexpected Operation/Multiple Payloads with similar readings
7	9/1/2012 9:15:44 AM	Second Spike	Current: 18.95 Voltage: 172.11	Unexpected Operation/Multiple Payloads with similar readings
8	9/1/2012 9:19:05 AM	System Shut Down	Current: 0 Voltage: 0.49	Decrease in Current and Voltage occurs gradually after second spike until Complete System Shut Down
9	9/1/2012 9:19:28 AM	First Intermittent Spike Post-Shut Down	Current: 0.47 Voltage: 1.1	Unexpected Operation/Multiple Payloads with similar readings
10	9/1/2012 9:21:20 AM	Second Intermittent Spike Post-Shut Down	Current: 24.25 Voltage: 314.81	Unexpected Operation/Multiple Payloads with similar readings (1)

As mentioned previously, it is not likely that the power spikes from the HASP power supply actually occurred; rather, they are anomalies in the data collection.

9. Power supply issue

The regulators and associated circuitry that supply power to the motors failed during flight. No power was being supplied. When system power is applied, no voltage is measured across the terminals of the motor power connector. The circuitry that applies power to all other parts of the payload still is entirely functional. So, if the circuitry internal to the payload caused the fuse to be blown, the failure cause was likely due to the circuitry that gives power to the motors. Even though there appears to be no short that would cause the payload to draw too much current, something due to the space environment very well could have caused the circuitry to act differently.

Through post-flight testing, the power draw necessary to blow the HASP Payload 10 fuse (greater that 30 V at 2.5 amps) could not be replicated. We have concluded that the extreme flight environment and the excessive temperatures of some components operating in vacuum prompted transients and abnormal power draw in the payload.

C. Thermal System

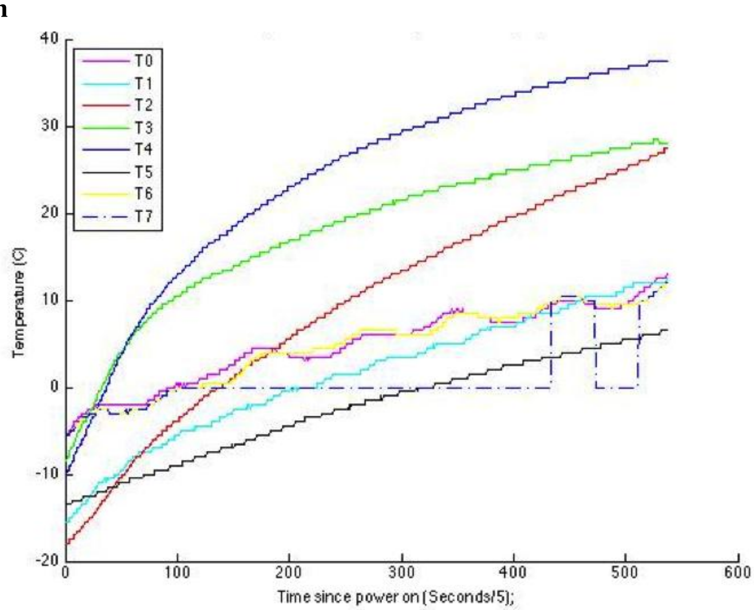

Figure 21: Temperatures of HASP Components During Flight

Table 3: Temperature Sensor Components Corresponding to Figure 21

Temperature Sensor	Component	Notes
T00	Camera 1	-5C to 12C
T01	Pitch Stepper Motor	-10C to 12C
T02	Computer	-10C to 27C
T03	Voltage Regulator	-10C to 27C Second Highest Reading due to
T04	Motor Driver 1	-10C to 38C Highest Reading due to
T05	Motor Driver 2	-10C to 5C
T06	SSD	-5C to 10C
T07	Camera 2	-5 C to 10 C

The thermal system was relatively stable, with the sensors reporting during the entire operational period. However, multiple sensors became detached from the components they were monitoring, and so the temperature readings in Figure 21 depict more “ambient” temperatures in close proximity to particular components. It is likely some components became much warmer during the course of the flight.

J. Attitude Determination and Control

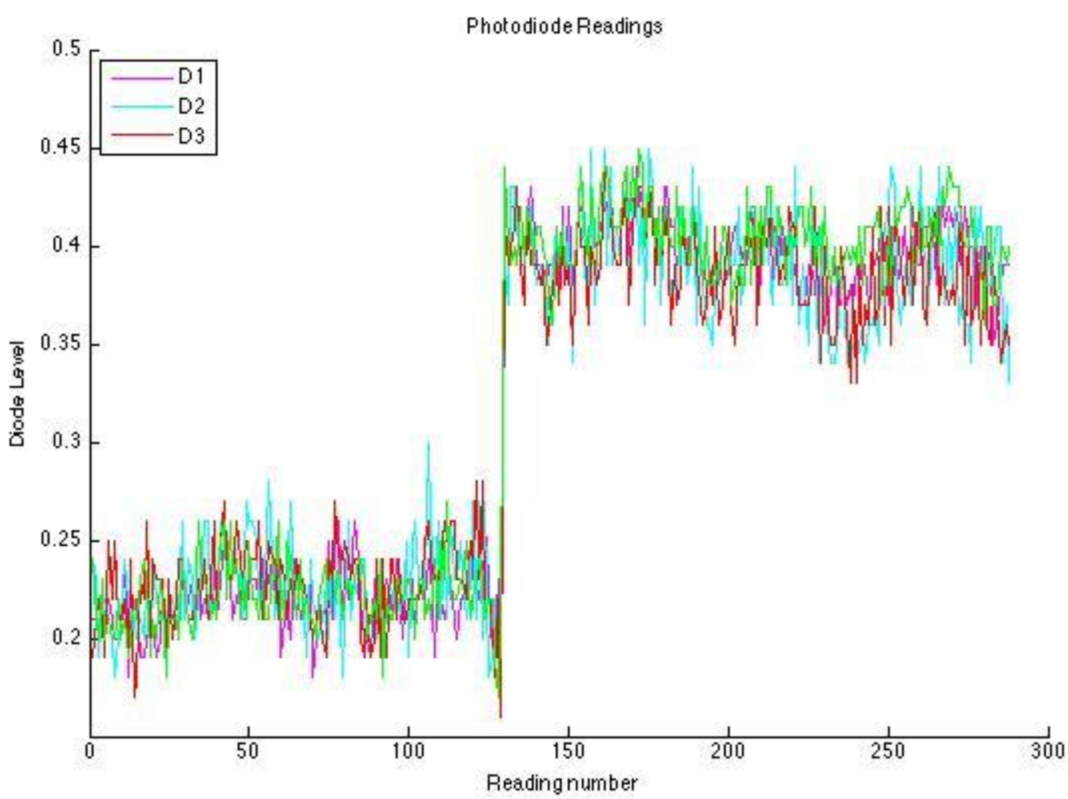

Figure 22: Photodiode Readings Throughout Flight

Because the attitude determination system was completely passive by the final design iteration, the only data collected from the system was in the photodiode readings.

Figure 22 shows the photodiode data for a duration of approximately 25 minutes of flight. All diodes were baffled and filtered similarly to decrease sensitivity and have a significant reading range to characterize the Sun. Due to time constraints the ADC system was not able to actively implement the photodiodes for solar tracking. The photodiodes were still used as sensors to possibly find any correlation between captured solar images and any significant events provided by the photodiode data during post flight analysis. The solar image captured was taken at about 11 minutes after power on. The major increase in photodiode reading occurs similarly at around 11-12 minutes, so it is a possibility that the Sun was in the field of view of the SHACK and the photodiodes at some time. After the first significant increase in photodiode readings the intensities remain within a high margin which provides inconclusive correlation after the 11-12min mark. There are various reasons of why this could have occurred.

If Voltage Regulator was failing and supplying less power to the system, the Arduino's reference voltage could have changed, altering the analog signal output. Conversely, it is possible that the light intensity at that point increased dramatically.

V. Team Organization

Table 4: Legend

ASEN	Aerospace Engineering
ASTR	Astronomy
ECEE	Electrical Engineering
MECH	Mechanical Engineering
Fr.	Freshman
So.	Sophomore
Jr.	Junior
Sr.	Senior
Gr.	Graduate
F	Female
M	Male

Table 5: HASP 2012 Team Members

Name	Year	Major	Gender	Ethnicity	Race
Gabrielle Massone	So.	ASEN	F	Non-Hispanic	Caucasian
Glenda Alvarenga	Jr.	ASEN	F	Hispanic	Caucasian
Jake Broadway	So.	ASEN	M	Non-Hispanic	Caucasian
Nicole Ela	So.	ASEN	F	Non-Hispanic	Caucasian
Jannine Vela	So.	ASEN	F	Hispanic	Caucasian
J.J. Busse	Sr.	ASTR	M	Hispanic	Caucasian
Ben Zatz	Jr.	ASEN	M	Non-Hispanic	Caucasian
Alberto Lopez-Dayer	Gr.	ASEN	M	Hispanic	Caucasian
Greg McQuie	So.	ASEN	M	Non-Hispanic	Caucasian
Brian Campuzano	Jr.	ECEE	M	Non-Hispanic	Caucasian
Zac Collver	Sr.	ASTR	M	Non-Hispanic	Caucasian
Vincent Staverosky	So.	MECH	M	Non-Hispanic	Caucasian
Gloria Chen	So.	ASEN	F	Non-Hispanic	Asian

Graduate Team Members

Name, graduation date, graduate degree, and current occupation (i.e. attending grad school at…, employed by company xxx doing yyy, etc…)

VI. Lessons Learned

A. Proposal Phase

System requirements:

During the preliminary design phase writing detailed requirements can be difficult. As the design progresses more, requirements should become more detailed. The purpose of system requirements is to have the ability to always verify if the level requirements are being met. Each requirement should be achievable, verifiable, unambiguous, and expressed in terms of a need and not a solution. To make a design change the system requirements should always be verified to assure that design would be fully applicable to all requirements. Do not allow hardware to determine your system requirements. All margins should be determined before purchasing/building/creating and hardware and software. Requirements should verify the reason for the hardware and software choices.

Schedule Internal Reviews during all phases of your designs:
The development of designs can be greatly improved by internal reviews at Space Grant or any internal review. Providing the greatest amount of information allows for more feedback. Don't feel discouraged presenting a design to someone that you're not sure about, anyone that shows up to your design reviews are excited to know what you are working on and are happy to help address any recommendations and help you think through your designs more in detail.

Limit moving parts:
If you are thinking about adding any moving parts to your system know that it will increase the complexity of the system tremendously; it does not matter if it is an off the shelf item. Try to limit the amount of moving parts used in the design – Keep It Simple.

B. Design Phase

Review Requirements:
During any major design change the requirements should always be verified. Sitting down with the entire team and going through each requirement to assure verification is very helpful to assure all requirements are covered and that there are no unnecessary over designs.

Address minimum success criteria:
Project schedules are made to be followed but some general aspects of designs may cause delays. (Lead times, manufacturing ability, design changes etc.) Due to this it is crucial to address minimum success criteria for a certain date. If for whatever reason all scheduled tasks were not fully met, a mitigation should already be established. It is always safer to have a plan B or C if plan A has proved itself to be unfeasible.

Communication:
Early within the design phase it is crucial to establish a means of communication between all team members. For HASP 2012 Drop box and Google Groups proved to be effective. Use whatever works best for the majority of team members. The Project Manager should keep the team updated on all changes or announcements, that way everyone will be accountable to always be on the same page. The Project Manager should have constant communication with the Systems Engineer, especially when tasks are slowly falling behind schedule, this helps on not only communicating more effectively throughout the team but also allows for mitigations to be planned with enough time.

Get to know your team members:
It is important to know the skills that each team member has. It is important to have someone with a special background applicable to the project within that subsystem to allow for progress to be made earlier in the design and be able to find potential system leads.. Keep in mind to not fully limit individuals since they may prove to be skilled at something they have never tried. For a more complex aspect (such as ADCS), keep a larger amount of team members focused in that subsystem but Project Managers should keep up with all progress in larger groups to assure the workload is spread evenly.

Challenge Team Members:
Don't be hesitant to allow others (or yourself) to try the part of the system that sounds the most challenging (scariest). The purpose of student lead projects such as HASP is to provide students the hands on experience of designing, creating, testing, and completing projects. The most rewarding part of these projects is that the entire process is challenging, they aren't meant to be easy. Be open to try something complex and new to you, you may be pleasantly surprised with the outcome.

Delegate:
Project Managers, do not be afraid to delegate directly to the team. It is crucial to maintain team member accountability and responsibility throughout the entire team (leads and individuals). As a project manager or team

lead, don't take on all the responsibility of assigning every single detail to every individual, that's why there are subsystem leads. Managers do need to know the constant status from them in case tasks are falling behind schedule to step in and delegate directly. Keep all tasks assigned within the public team schedule with "person responsible" listed as well as status of each task (in progress, completed, past due), and allow leads to update it so the entire team feels accountable for team success.

Take pictures and video:
In the moment taking the time to take pictures or video may seem like an unnecessary use of time, but in hindsight it is one of the most helpful things you can do. Pictures are great for documenting the status of the system before and after changes. Pictures can sum up an entire test, something that is very useful when documenting what happened during the test later. Videos are great to have as a memory of what you accomplished and are fun to show off.

Have Weekly Team Meetings:
Schedule general update team meetings, this will allow for finding out if assigned weekly goals have been met and if they haven't, what is being done to be back on schedule by the person responsible.
At these meetings the Manager and Systems Engineer should clearly know what the next weeks' goals should be and announce them to the team. After announcing them it is crucial to document them in the team schedule.

Milestones:
It is important to have an overview of what needs to be done at a high level perspective. For example if Integration Testing for HASP is in July, the milestone before that should be "full functionality testing complete by end of June". It is easier to schedule tasks by having general milestones laid out to prepare for any schedule delays or design mitigations. It also helps the team be aware of the overview of how the project should progress.

Special Requests:
Inform launch operators about special requirements early. If your project has special requirements (needs more power, faster communication rate, breaks the physical limitations of the payload space), tell your launch personnel as soon as possible. They will not only help think of mitigations for your request to assure its necessary and feasible but if they are informed with enough time they will be more willing accept it.

Stay busy:
No matter how ahead of schedule you may be, keep working. Delays will occur when their least expected. There should never be a team member that says he/she has nothing to do. If that's the case, Mangers need to verify the tasks needed to be done within their assigned subsystem or see if a different subsystem can use another hand. Project Manager and Systems Engineer should keep all future possibilities in mind (Interfaces, Flight Operations, wiring plan, thermal shorting plan, etc) to be prepared to work ahead of time.

C. Manufacturing Phase

Keep referring to requirements:
During the Manufacturing plan it is important to always check system requirements to assure they are fully met and not overdone. The simpler the design the less complex it will be to interface and integrate, do not over-design unless there is absolutely enough time and is approved by all team members through all levels.

Team Accountability:
Having a method to keep track of all progress is extremely important at this point. One piece of hardware/software is reliant on another and another and another. Having one fall behind can delay the entire project. As mentioned before having a public schedule that specifies the person responsible and status of the task is important. But these tasks need specifications that describe what complete should be. Hold team member accountable by having them present their progress to the team (during meetings, demo-days and reviews).

Keep all Documentation Organized and Up to Date:
Team Schedule, Mission Requirements, In-progress deliverables, Documented Subsystem Weekly Reports, Data Sheets, Testing Plans, Testing Results, etc All Need to be in one file system that every team member should be capable of using. It is also important to keep all of these files uniform per subsystem to assure all documentation exists, and is relevant. If ideas and designs are not documented and available to the entire team they DO NOT

EXIST.

Demo-days:
When subsystems are in the middle of developing their designs it is helpful to beneficial to have subsystems present what they have progressed on. Not only does this provide accountability,
but it also helps motivate the rest of the team on progressing and seeing the results of their hard work which is motivating.

General Book Keeping:
Project Manager needs to be able to stay updated on all project expenses and lead-times for parts. It is crucial for System Leads to provide reasons of choosing a product to purchase with appropriate time to be approved by the Systems Engineer and then be fully approved by the Project Manager.

D. Integration & System Testing

Document Testing Procedures and Results:
When testing a system or component, through a document it is crucial to write a test procedure to understand exactly what it is that is specifically being testing. After testing all results need to be document. Remember to always refer to system requirements to fully understand what needs to be tested and site that requirement in the testing procedure. Keep in mind that these testing procedures and result will possibly be referred to in the future by the individual(s) conducting the test or someone that was not even present during that test. Write things out clearly.

Test smallest to largest:
Test as often as possible, test individual components (in-house or off-the-shelf). Test when two components are integrated, three components and so on. This is crucial so that when a test provides unexpected results it is easier to debug and single out a cause. As mentioned before document all testing. Some components may work individually and may fail when integrated, this is why a fully integrated system test is important prior to integration testing to not allow for the possibility of having a failing integrated payload with multiple unknown causes.

Reliance on Team Members:
On every complex system (i.e. Software & Electrical), it is crucial to have more than one person be aware of the fine details of that system. There are possibilities where one extremely crucial team member may become un-available or leave the project which can harshly cripple the team. Apart from having more than one person responsible for a complex aspect of a system, documentation is also extremely important. (Even knowing how to run a script for testing on a Linux terminal)

System Status:
Project Manager and Systems Engineer need be aware of the complete system status and help in keeping the team updated on any test success (Testing Status Spreadsheet), test failures, design changes, mitigations, etc that have been done throughout the testing phase. All systems rely on each other in some way so it is important for everyone to be aware of major events to troubleshoot or move forward earlier.

Day In The Life (DITL):
Once the payload is integrated and working in at room temperature, standard pressure environment, test it under flight conditions (or as close as you can get to flight conditions). This includes, cold testing, Vacuum Testing, Thermal Testing, and running payload processes for the amount of expected flight. This can aid in troubleshooting any issues that may arrive such as overheating, or power issues.

- To complete DITL all environment margins need to be addressed (i.e. Thermal Vacuum testing details for Integration testing)
- Request this information from the HASP program early if it is not given to you.

E. Flight/Post-Flight

Make verification methods internal:

It is a good idea to make sure that you can verify things about your system independently from the HASP platform. (i.e. collect on-board voltage and current draw)

Concept of Operations and Flight Operations:
Know exactly what needs to happen when, you don't want to waste any flight time developing a plan of action. Anticipate what can go wrong, and what you can do to fix it.

Develop post-flight analysis early:
Something to ease the data analysis process is to have team members develop a post-flight analysis plan early. Good to keep team members busy, and relieve some work after the long hours from launch and final integration.

F. General Lessons

Ask Questions:
If you do not understand something, ask about it! It is definitely better to look like you are interested in knowing more about something you don't fully understand. Do not be discouraged if you don't understand something or need help. If you have peers, mentors, even general staff at Space Grant, they will be more than willing to help you or point you in the right direction. Just ask.

Scheduling:
Keep all schedules and tasks up to date. Make them achievable, Project Manager and Systems Engineer should be readily available to help in any aspect of the project. For time periods where many small tasks need to be complete (i.e. prior to Integration Testing), a burn down list (checklist) is easier to go through to check off small tasks as they are completed sine there will most likely be many of them.

Team Presentations:
Have team members show off and present their hard work; it will motivate them to reach deadlines and give them an opportunity to be proud of what they've done. It also motivates the rest of the team to work next to others that working hard and care about the quality of their work and success of the Mission in general.

Main Lesson:
Do not forget why you are doing this. There will be late nights and times where you have to sacrifice hanging out friends to finish the project, but remember how fun it is to be working with your hands and designing something that is going to space! Not many students get this opportunity, make the most of it! Launch makes it all worth it.

VII. Conclusion

The initial primary goal of the HELIOS payload was to determine whether the use of Hydrogen-Alpha or Calcium Potassium solar imaging would gather accurate images at float altitude. Also, the secondary goal was to analyze the solar aspects through imaging and compare them to a ground based facility to verify image correlation. Throughout our mission we were able to capture images of the Sun at float using the SHACK system, but due to lack of proper filtering and optic condensation we were unable to gather accurate images at altitude. However, our ground calibration testing did provide proof of the capability of capturing solar aspects in the Hydrogen-Alpha wavelength. The HASP 2013 team is proposing the mission HELIOS II which if accepted, will have the opportunity of improving the HELIOS optics to capture accurate solar imaging at float, as well as implement an active attitude determination and control system. The improvement of the HELIOS optics and ADC system will not only capture accurate images of the Sun at float, but will also aid in proving the feasibility of balloon based solar observatories.