Colorado Space Grant Consortium

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Colorado Space Grant Consortium
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Dear Dr. Guzik

Thank you for taking the time to read our proposal and for considering our payload for 2014. We look forward to hearing from you. The results of University of Colorado at Boulder's HELIOS I and HELIOS II have given us cause to conduct further research into high altitude observatories. This years HASP 2014 team has taken into consideration the concerns with both HELIOS I and II and has re-designed HELIOS to offer an improved mission (HELIOS III) to observe the sun in hydrogen-alpha wavelengths and improve upon balloon based attitude determination and control systems. The HASP platform is the most suitable method to test our re-designed high altitude solar imaging payload and to compare to results from ground and orbital observatories. Thank you for providing this opportunity for student research.

Sincerely the 2014 team:

Christopher Rouw	Cooper Benson	Paige Arthur
Griffin Esposito	Ryan Patton	Tyler Lugger
Mattia Astarita	Dylan Richards	Andrew McBride
Chris Bradford	Caleb Lipscomb	Jorge Cervantes
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HASP Student Payload Application for 2013

Payload Title: HELIOS III		
Payload Class: (check one) ☐ Small ■ Large	Institution: University of Colorado Boulder	Submit Date: 12/20/13

Project Abstract

HELIOS III shall observe the Sun in Hydrogen-Alpha wavelength. Observations in this wavelength on the ground are hindered by atmospheric interference. HASP will ascend above 99.5% of the Earth's atmosphere, eliminating this issue. The HASP platform offers a low-cost alternative for solar observations. Additionally, the HASP platform has an extended float time that will give the payload more time to observe the Sun than a regular high altitude balloon flight. This is a re-fly of the University of Colorado's 2012 and 2013 HASP teams' missions, HELIOS I and HELIOS II. HELIOS III is attempting to re-fly the mission to overcome the technical issues that hindered the HELIOS I and II teams as well as improve upon the science results. HELIOS III will focus on improving the Optics, Attitude Determination and Control System, Command and Data Handling System and Electrical Power System of HELIOS I and II. HELIOS III aims to improve the reliability of these three systems, and utilize the full float operations capability of the HASP Platform. Due to the weight and size of the HELIOS III payload, a large payload seat is necessary for this mission.

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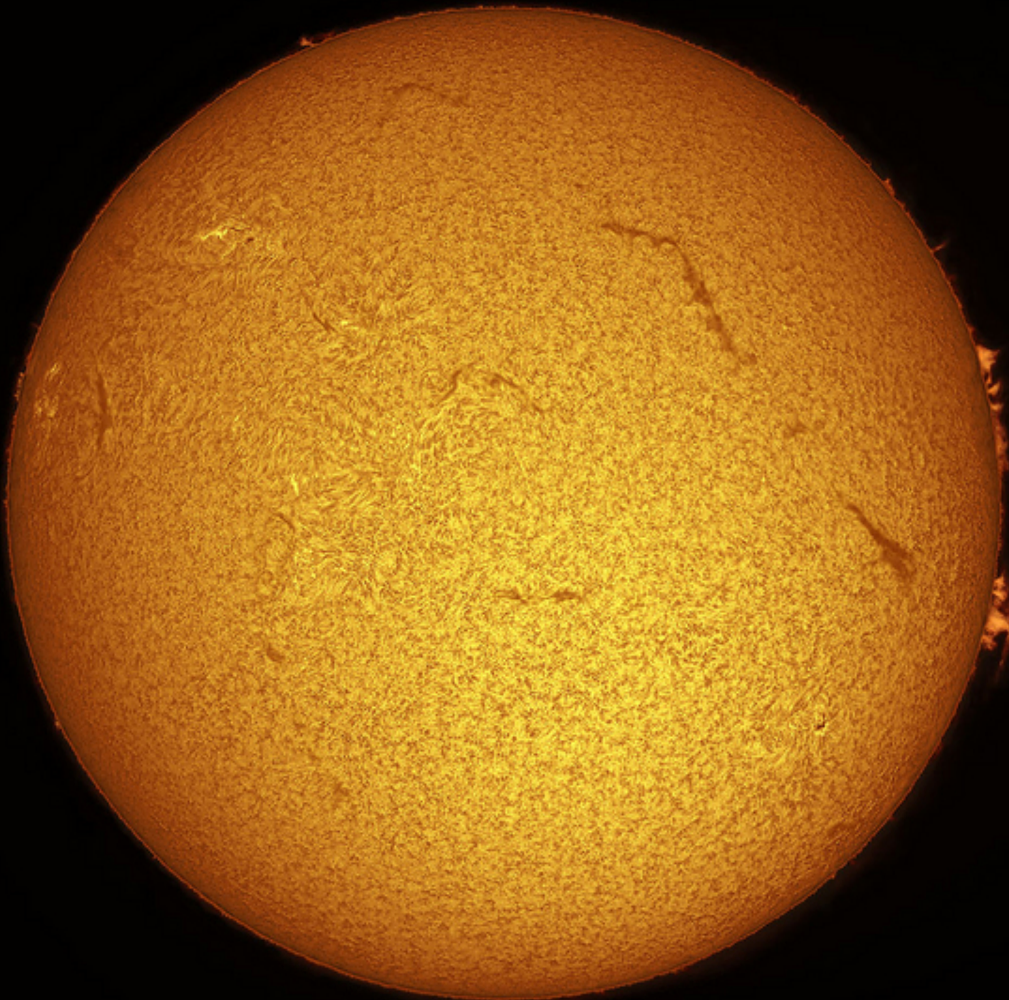

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HELIOS III

Team Icarus - Dylan Richards, Christopher Rouw, Paige Arthur, Griffin Esposito, Andrew McBride, Cooper Benson, Chris Bradford, Mattia Astarita, Ryan Patton, Tyler Lugger

HASP 2014

12/20/13

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2 MISSION OVERVIEW

2.1 MISSION OBJECTIVE

Team Icarus shall design and construct the Hydrogen-Alpha Exploration with Light Intensity Observation System (HELIOS) III containing a Solar Wavelength Imaging System (SWIS) capable of capturing images of the Sun in the Hydrogen Alpha wavelength and utilizing an Attitude Determination and Control System (ADCS) to locate the Sun and orient the SWIS towards the Sun on-board a HASP flight.

Primary Mission Requirements:

1. Observe and capture images of the Sun in Hydrogen Alpha wavelength using the SWIS system.
2. Improve the HELIOS II design of the ADCS system to locate the Sun in the sky and orient SWIS towards the Sun.
3. Design a high altitude balloon solar observation platform for a Colorado Space Grant Consortium (COSGC) sponsored HASP flight.

2.2 MISSION PREMISE

Currently, the majority of solar observations are performed using ground or orbital telescopes. These two methods of observing the Sun have many drawbacks. Ground observations face issues with interference from the atmosphere, reducing the quality of solar images and the amount of accurate scientific data collected from those images. Orbiting observatories are very expensive, limiting the quantity of such solar imaging missions and, by extension, the number of high-quality solar images. With these restrictions in mind, an alternative method to view the Sun is with high altitude balloon observatories. High altitude balloons are a relatively inexpensive platform and can travel above 99.5% of the Earth's atmosphere, mitigating the effect of atmospheric interference during solar observations.

The Colorado Space Grant Consortium (COSGC) at the University of Colorado at Boulder (CU) has a history of high altitude observatory experiments. DIEHARD (2008) determined the viability of high altitude observatories by collecting diurnal and nocturnal images of celestial bodies to determine atmospheric turbulence and light intensity due to residual particles in the atmosphere. This was done using photometers mounted 45-degrees from the horizon. BOWSER (2009) further determined the practicality of high altitude observatories by examining certain wavelengths of cosmic light and took corresponding diurnal images and light intensity readings of the sky. BOWSER also measured platform stability in order to determine the conditions in which future HASP missions will fly. SPARTAN-V (2010) worked towards the goal of supporting precise photometry from balloon based pointing systems and telescopes. SPARTAN-V focused on characterizing atmospheric scintillation to support the practicality of observing exoplanets from a high altitude balloon.

In 2012, the University of Colorado Boulder HASP team, HELIOS, flew a similar mission to test the viability of solar observation on a high altitude balloon platform. However, several issues hindered their mission. The HELIOS team was unable to finish the design and testing of the ADCS. The team also had outgassing that caused fogging of the camera lenses. Additionally, the team experienced a power issue causing the payload to overdraw current, which subsequently disabled all systems.

In 2013, a team flew HELIOS II to accomplish similar mission objectives while addressing the problems found on HELIOS I. The HELIOS II team implemented a new ADCS utilizing photodiodes, carefully tested for outgassing problems, and created external protection circuits to disable systems drawing more than their allotment of power. Problems were also encountered by the HELIOS II team that involved several systems overheating, the ADCS system being confused by reflections off the balloon, reliability issues in the Command and Data Handling system, including cameras with unsupported drivers, and a lens configuration that forced the payload to surpass the height restriction.

The HELIOS III team plans to build upon the mission objectives of HELIOS I and II while correcting the issues encountered in flight by these teams by:

1. HELIOS III will use the ADCS camera in combination with the photodiodes to track the Sun.
2. The final structure and components of HELIOS III will be tested in a thermal vacuum chamber to detect any outgassing before launch. In addition, HELIOS III will practice clean building procedures in the construction and assembly of the payload.
3. HELIOS III will implement external power controls similar to those flown by HELIOS II that will be controlled by the main flight computer. These controls will be electronic switches controlled by an Arduino, which can be toggled either by ground commands or by the Arduino if it detects any system overdrawing power.
4. HELIOS III will manage the extreme temperatures experienced during the day by applying heat sinks to all high temperature components and transferring that heat to the structure and HASP platform (if allowed by HASP).
5. HELIOS II flew a PandaBoard, which did not perform as expected on the flight. It was also poorly suited for the mission in that it had only one communication line for connections to the Arduinos, requiring a communications protocol that did not work as expected for the computer to communicate with both Arduinos. To resolve these problems, HELIOS III will be flying a Raspberry Pi instead, because it is better suited for the mission. Team Icarus has determined the compatibility of this computer with the camera drivers. The Raspberry Pi also has a set of input and output pins crucial for running the ADCS system and connecting to an Arduino and will be smaller in size than the PandaBoard.

2.3 Photometry

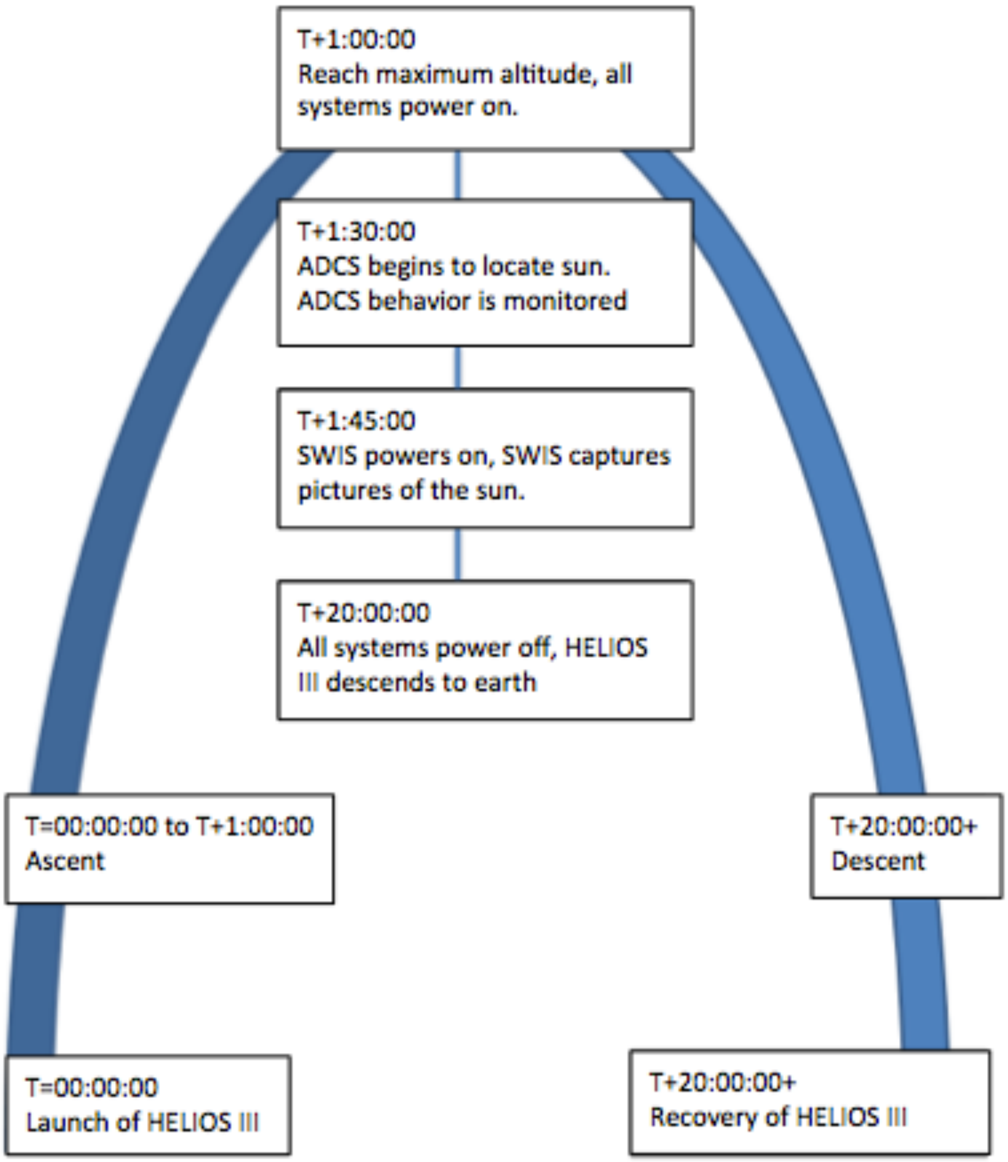
The Solar Wavelength Imaging System (SWIS) shall image in the Hydrogen-Alpha (H-Alpha) spectrum (656.3 nm) and shall have a resolution such that images of solar features such as sunspots and granulation can be clearly seen.

H-Alpha filters allow the camera to detect only red light at a wavelength of 656.3 nm. These wavelengths are emitted when a high-energy electron within a hydrogen atom falls from the third to the second energy level, primarily in ionized hydrogen clouds. However, surrounding wavelengths typically drown them out in unfiltered cameras.

H-Alpha is a useful wavelength for solar imagery, as it allows the observer to see granulation, sunspots, and solar flares. H-Alpha exists in two layers of the Sun: the Photosphere and Chromosphere. The Photosphere lies at the lowest level and the Chromosphere is the mid layer of the Sun's atmosphere. H-Alpha gives a reddish color to the Chromosphere, but this is generally not observable during normal conditions as the Photosphere is too bright. Thus, solar phenomena are only observable in the

Photosphere. H-Alpha, however, allows the viewer to observe solar features in the Chromosphere, thus allowing a greater analysis of solar activity in the Sun. HELIOS II was unable to capture granulation in the partial image captured during its flight because magnification did not meet the Rayleigh Criteria. HELIOS III hopes to capture all three features, but solar flares are relatively rare. However, if HELIOS III can capture full solar images, sunspots and granulation should be apparent.

2.4 Principle of Operations



HELIOS III shall have all systems verified prior to launch. HASP integration shall occur one day before launch. HELIOS III shall then launch the following day and rise to an estimated altitude of 36,500 meters after approximately one hour of flight. All systems shall then power on as it reaches this maximum float altitude. All systems shall be monitored by the team on the ground for 30 minutes. After 30 minutes at maximum altitude, or one hour and 30 minutes into flight, HELIOS III shall locate the Sun with the use of its ADCS. HELIOS III shall monitor the behavior of the ADCS for 15 minutes to insure that the ADCS is operating properly. Upon verification that the ADCS is functioning properly, the SWIS shall power on. HELIOS III shall be one hour and 45 minutes into the flight at this point. HELIOS III shall then capture pictures of the Sun until the twentieth hour of flight. Blackout periods will occur when the internal temperature, as measured by the environmental sensors, exceeds 60 degrees Celsius. The payload will also be powered down when the HASP balloon hinders HELIOS III's line of sight on the Sun. The duration and degree of elevation of the SWIS camera at this period is currently undetermined. All systems shall then power down and HELIOS III shall descend down to Earth.

3 Requirements

In order to complete all mission goals, HELIOS III shall abide by all requirements specified by HASP, in addition to all requirements derived from mission objectives. The success or failure of HELIOS III shall be incumbent upon the adherence to and verification of the following statements.

3.1 Zeroth Level Requirements

LEVEL	REQUIREMENT	DERIVED
0	Hydrogen-Alpha Exploration with Light Intensity Observation System (HELIOS) III containing a Solar Wavelength Imaging System (SWIS) capable of capturing images of the Sun in the Hydrogen Alpha wavelength and utilizing an Attitude Determination and Control System (ADCS) to locate the Sun and orient the SWIS towards the Sun on-board a HASP flight.	

3.2 First Level Requirements

LEVEL	REQUIREMENT	DERIVED
0.1	Observe and capture images of the Sun in Hydrogen Alpha Wavelengths	Objective
0.2	Design and implement an ADCS to locate the Sun and orient the SWIS toward the Sun	Objective
0.3	Design a high altitude balloon solar observation platform for a COSGC-sponsored HASP flight	Objective

3.3 Second Level Requirements

LEVEL	REQUIREMENT	DERIVED
0.1.1	SWIS shall implement a filter allowing imaging of 656.28 nm wavelengths	0.1
0.1.2	SWIS shall implement a camera capable of gathering high resolution Hydrogen-Alpha images	0.1
0.1.3	SWIS shall allow for storage of captured images	0.1
0.1.4	One camera shall have a large field of view with low magnification for use by the ADCS	0.1
0.1.5	One camera shall have a small field of view with high magnification for solar imagery	0.1
0.1.6	SWIS shall be insulated and isolated from all other systems' thermal footprint	0.1
0.1.7	SWIS Cameras shall be compatible with the HELIOS III main CPU.	0.1

LEVEL	REQUIREMENT	DERIVED
0.2.1	ADCS shall monitor changes of the Sun's orientation along the Theta and Phi axes	0.2
0.2.2	ADCS shall use motors to orient SWIS in the direction of the Sun	0.2
0.2.3	ADCS shall be capable maintaining the Sun within the field of view of SWIS	0.2
0.2.4	ADCS shall be designed with consideration to thermal effects on materials	0.2

LEVEL	REQUIREMENT	DERIVED
0.3.1	HELIOS III shall comply with all HASP requirements outlined by the Call for Proposal	0.3
0.3.2	HELIOS III shall comply with all budget and schedule constraints dictated by COSGC and HASP	0.3
0.3.3	HELIOS III shall maintain a proper operational environment throughout flight	0.3

3.4 Third Level Requirements

LEVEL	REQUIREMENT	DERIVED
0.1.4.1	The ADCS camera shall have a field of view no less than 15 degrees x 10 degrees	0.1.4

LEVEL	REQUIREMENT	DERIVED
0.1.5.1	The Science camera shall have a field of view of 1.5 degrees x 1 degree	0.1.5
0.1.5.2	The Science camera shall have a resolution of greater than 2500 pixels x 2000 pixels	0.1.5

LEVEL	REQUIREMENT	DERIVED
0.1.6.1	SWIS shall remain below 60 degrees Celsius throughout the flight	0.1.6

LEVEL	REQUIREMENT	DERIVED
0.2.1.1	ADCS shall record Sun's orientation in the Phi plane every tenth of a second	0.2.1
0.2.1.2	ADCS shall record Sun's orientation in the Theta plane every tenth of a second	0.2.1

LEVEL	REQUIREMENT	DERIVED
0.2.2.1	ADCS motors shall be capable of rotating SWIS by 3 degrees per second	0.2.2

LEVEL	REQUIREMENT	DERIVED
0.2.3.1	ADCS Phi motor shall have a precision of at least 0.2 degrees per step	0.2.3
0.2.3.2	ADCS Theta motor shall have a precision of at least 0.04 degrees per step	0.2.3

LEVEL	REQUIREMENT	DERIVED
0.2.4.1	Theta and Phi motors shall remain below 60 degrees Celsius throughout flight	0.2.4

LEVEL	REQUIREMENT	DERIVED
0.3.1.1	Payload volume shall not exceed 38x30x30 cm	0.3.1
0.3.1.2	Payload shall resist the effects of up to 10 g vertical force and 5 g horizontal force	0.3.1
0.3.1.3	Payload shall utilize a twenty-pin EDAC 516 interface to HELIOS III system power and analog downlink channels	0.3.1
0.3.1.4	Payload shall not draw more than +30 VDC or 2.5 amps and shall split the provided +30 VDC to voltages necessary to operate payload	0.3.1
0.3.1.5	Payload shall enable six discreet command functions from HASP using EDAC 516-020 interface	0.3.1
0.3.1.6	Payload shall allow serial downlink functioning at 4800 baud	0.3.1
0.3.1.7	Serial up-link shall allow for 2 bytes per command	0.3.1
0.3.1.8	Payload shall use a DB9 connector, RS232 protocol, with pins 2, 3 and 5	0.3.1
0.3.1.9	Payload shall transmit payload status to the HASP serial downlink	0.3.1
0.3.1.10	Payload shall be mounted according to the HASP platform interface requirements	0.3.1

LEVEL	REQUIREMENT	DERIVED
0.3.2.1	All receipts and proofs of purchase shall be retained	0.3.2
0.3.2.2	Schedule shall include weekly deadlines for each phase of design, assembly, and integration process	0.3.2
0.3.2.3	Schedule shall include all design document revisions; including relevant presentations	0.3.2
0.3.2.4	Schedule shall contain weekly team meetings	0.3.2

LEVEL	REQUIREMENT	DERIVED
0.3.3.1	SWIS structure shall be insulated to minimize thermal footprint of other systems	0.3.3
0.3.3.2	All systems shall remain within operating temperatures while experiencing external temperatures between -80 to 60 °C	0.3.3

4 DESIGN OVERVIEW

HELIOS III includes the Solar Wavelength Imaging System (SWIS), an Attitude Determination and Control System (ADCS), an Electronic Power System (EPS) and a Command and Data Handling system (C&DH). SWIS is a two-camera array that captures images of the Sun in Hydrogen-Alpha with a high resolution camera and uses the second, lower resolution camera to track the Sun. The ADCS is a two-axis control system. The ADCS shall adjust the azimuth elevation of the SWIS; the imaging system shall be mounted on a circular plate with a full 360-degree range of rotation. The combination of these two elements shall allow SWIS to track the Sun and ensure the Sun remains in the field of view of the SWIS. The EPS system shall provide power to all other systems on HELIOS III and regulate the current draw of all systems. The C&DH system shall control all other systems and monitor the status of those systems. The C&DH and EPS shall be located underneath SWIS, separated from the ADCS system. All subsystems will be supported by a machined aluminum structure. The aluminum structure shall maintain the structural integrity of HELIOS throughout launch, float, and landing. The design of HELIOS III is most suited for a large 20 kg payload, situated in any of the four large payload spots.

4.1 Solar Wavelength Imaging System (SWIS)

The objective of SWIS is to capture images of the Sun and filter all incoming radiation outside of the Hydrogen-Alpha wavelength. SWIS consists of the ADCS camera and the Science camera. The ADCS camera is a UI-1240SE Monochrome CMOS camera (figure 4.1) with a high frame rate of 25.8 frames per second (fps) in order to better track the Sun and low resolution (1280 x 1024 pixels). The Science camera is a UI-1480SE Monochrome CMOS camera (figure 4.1) with only 6.3 fps and a higher resolution (2560 x 1920 pixels) in order to collect better quality images of the Sun than those collected by HELIOS II. The cameras selected are Linux 2.6 compatible. Each camera is C-mount compatible allowing the science lens to be easily connected to the camera. The Science camera shall successfully filter out unwanted EM radiation using dichroic filters to filter out unwanted wavelengths of light (IR and UV light), a narrow band-pass filter, with a 10 nanometer bandwidth (passes light at 656 nanometers), and a neutral density filter with an optical density of three, to decrease the intensity of incoming light to one-one thousandth of the original intensity, in order to maximize image clarity. The ADCS camera shall use the same dichroic and neutral density filters, but a specific band-pass filter won't be necessary for tracking the Sun. Each camera is fitted with barrels containing each of the filters and the magnification system with standard C-mount threads and coated with black anodized aluminum. The color black shall act as a baffle to prevent reflected light from the inside of the tube falling on the lens, while anodized aluminum should minimize outgassing. Two different barrel lengths shall be used: one long and one short. This shall allow for the ADCS camera to have a wide field of view and a low resolution, and allow the Science camera to have a high resolution but a small field of view. The ADCS camera shall be used as the micro track sun tracker. The Science camera shall be used to produce high-resolution images to be compared with those from ground-based and orbital observatories, such as NCAR's High Altitude Observatory (HAO) and NASA's SOHO satellite.

Figure 4.1 Image of Cameras (Both ADCS and Science use the same camera housing)

The two SWIS cameras shall be mounted on the rotating rig below the Theta (θ) photodiode array. The Phi (φ) array shall be alongside the camera rig. It shall operate during the float phase to reduce the rotation of the platform. This will ensure minimal blurring of the image and maximize the exposure time to the Sun, allowing for more images of the Sun to be captured. This mission design consideration, along with the long focal length shall produce high-resolution solar images.

Since it is the mission of HELIOS III to observe sunspots and granulation on the surface of the Sun, the Science camera must focus on being able to recognize the granulations, because they are much smaller than sunspots. The Sun's diameter is approximately 1.39*10^6 km and is on average 1.50*10^8 km from Earth. At this distance, the Sun's angular diameter is about 0.536 degrees. The average size of a granule on the Sun is about 1000 km, and it requires three pixels (one for each granule and one in between) to identify a difference in granules. In order to encompass smaller than average granules, two granules added to be about 1500 km, with three pixels required to distinguish them, requires a magnification system on the Science camera that depicts the Sun at 500 km per pixel. This means the Science camera magnification system needs to produce images at 0.0001935 degrees per pixel in order to examine the Sun's granulations. After capture, these images shall be stored on an external disk. The images captured in flight shall be compared with photos from current ground observatories and ground test images from SWIS to assess their relative quality.

4.4.1 SWIS Lens System

To avoid the SWIS system from breaching the height requirement of large payloads on the HASP platform, the lens system for the Science camera will need to be made with a shorter body that preserves the focal length required for proper images of the Sun. This will prevent the system from exceeding the height requirement when rotated into a higher inclination. A Cassegrain Configuration uses a system of a parabolic mirror and a small convex mirror to focus the incoming light from the Sun into the CMOS chip on the Science camera. The use of this configuration will shorten the length of the lens system significantly compared to the 250 mm length last year. One drawback with this system is that it would widen the lens system to 100mm. This would not interfere with the height of the system and adaptions can be made mount the lens system onto the c-mount compatible cameras. This system will use the 100mm diameter parabolic reflector positioned 12.5mm away from a 25.4mm diameter convex mirror. This distance is based off the focal length of the parabolic mirror. The convex mirror will have a radius of curvature of 25mm. The focal point from the convex mirror to the CMOS chip in the Science camera will be 17mm. This system will be under 45 mm long in total, which is a significant change from the original 250mm long lens system used in HELIOS II.

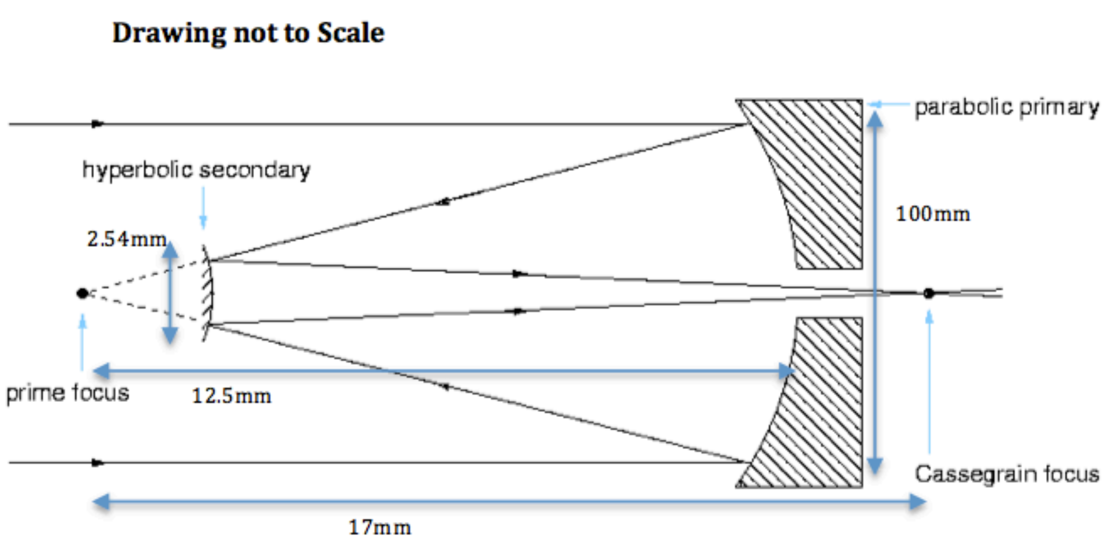


Figure 4.2 Cassegrain Lens Configuration

4.2 Attitude Determination and Control System

ADCS shall be responsible for maintaining the Sun within the field of view of the two-camera imaging system. This shall be accomplished via the ADCS camera, and two-axis photodiode array system that shall transmit a certain output voltage depending on the intensity of light that is read. These voltage readings shall be used to determine the position of the camera housing in relation to the Sun and make the necessary corrections to allow for accurate imaging. The attitude determination shall depend on these two arrays to track the motion of the Sun, taking into consideration the rotation and movement of the HASP platform during flight as well as the movement of the Sun as it moves across the sky. The ADCS camera will be used for the micro tracking of the Sun and will focus SWIS on the Sun.

4.2.1 Solar Position Determination

A two-array system shall be used to track the Sun. The first, a Theta photodiode array has arms that are angled 90° from each other. Each arm contains two photodiodes, one main pair and one back-up pair. Each pair of photodiodes is located at the same distance on the arm from the base of the array. The Theta array shall be mounted below the imaging system and shall rotate along with the camera housing on the Theta plane. The second, a Phi photodiode array, is equivalent in design to the Theta photodiode array. This shall be mounted to the side of the imaging system and shall also rotate on the Phi-axis with the imaging system. This is done so that when the imaging system is oriented in the Phi-axis, the Phi photodiode array is also oriented to face the Sun.

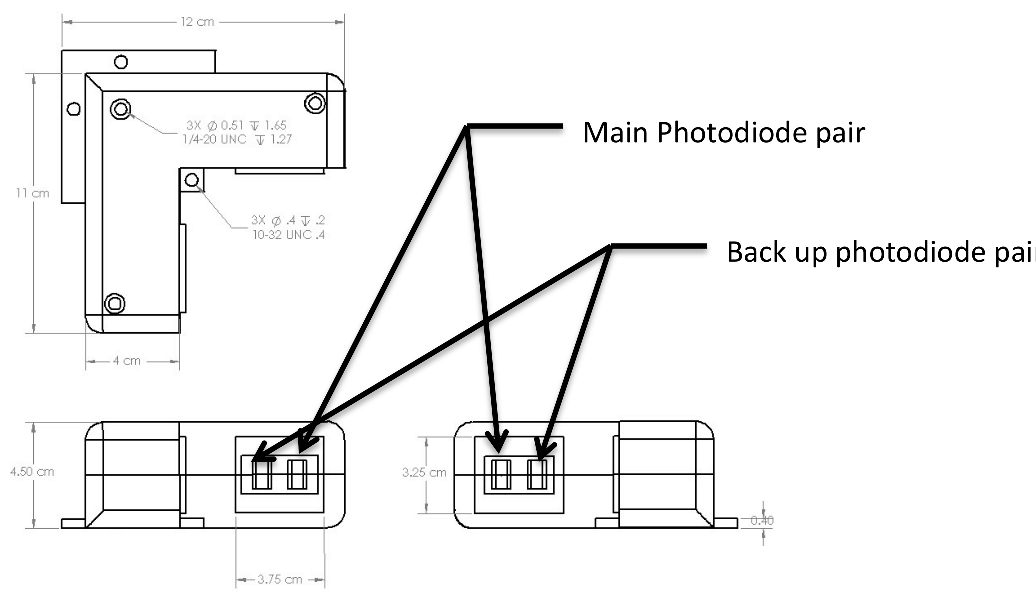


Figure 4.3 Photodiode Housing

Because the photodiodes would be saturated when looking at the Sun, four layers of composite filters coated with an acrylic polymer shall be implemented on each photodiode. Operational amplifiers, or op amps, shall be used to amplify the photodiode output signal. Upon amplification, the photodiodes shall have a maximum output of 2.8 V and a minimum of about 0 V. The Arduino microcontroller shall supply the power required for the op-amps.

One of the issues that the HELIOS II team experienced, which ended up being detrimental to the success of the mission, was unexpected sunlight reflected by the balloon, giving the photodiodes on the Phi-axis false readings when determining the position in relation to the Sun. These faulty readings caused the control system to fail to orient the imaging system so that the Sun was in the center of the field of view, which caused the Science camera to fail to gather images of the Sun.

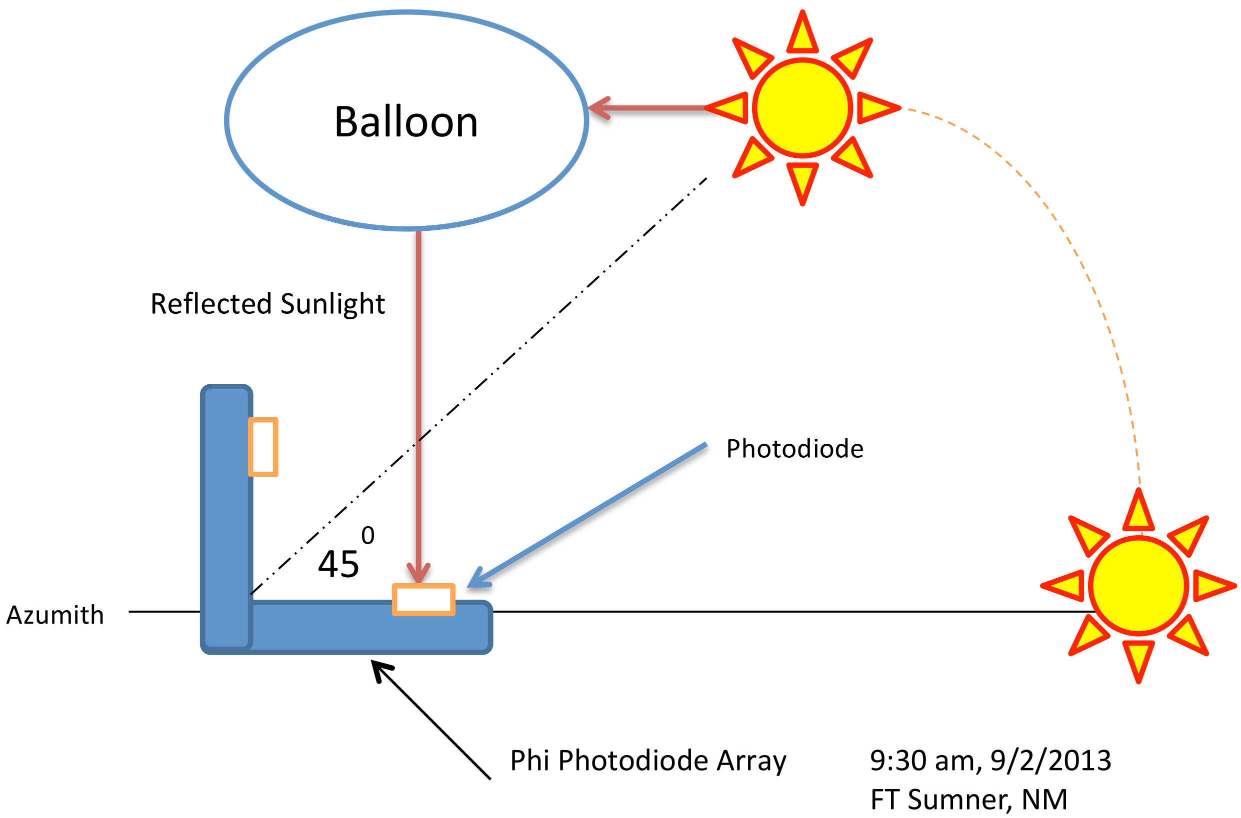


Figure 4.4 Photodiode Failure Analysis

To solve this issue, the design will be improved so the system is less prone to interference with the surrounding environment. Because the photodiode array system for last year's HELIOS II team was able to orient the Sun near the center of the field of view of the science camera, HELIOS III shall continue to use this system to macro track the Sun. However, the ADCS camera shall be responsible for micro tracking the Sun. The ADCS camera will not be affected by reflections off the balloon as it will be searching specifically for a circular light of a particular size rather than light in general The ADCS camera's FOV is more restricted than the photodiode arrays, and the ADCS camera's filtration allows it to only view light from the Sun.

4.2.2 Rotation and Positioning

Two motors shall be used to rotate the imaging system, allowing it to focus on the Sun in a direction determined by the Theta-plane and Phi-plane arrays. One motor shall orient the system on the Theta-plane and the other motor shall orient the cameras along the Phi-plane. The system shall have an overall reaction time of 1-3 seconds, which will vary depending on the degree of rotation. The system shall be able to respond fast enough to the platform rotating at a speed of up to 1.2 to 2 degrees per second.

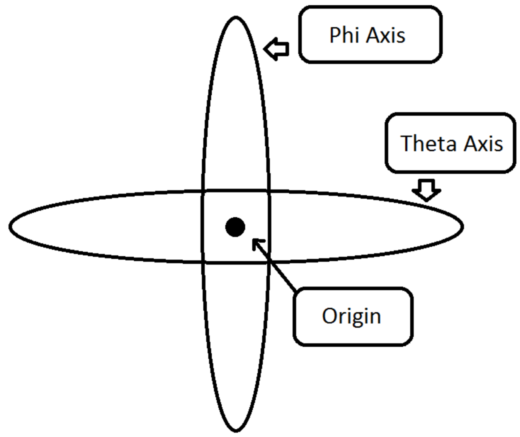


Figure 4.5 Motor Planes

4.2.2.1 Theta-Plane (Θ) Motor System

The Theta-plane motor system orients the direction of the imaging system in the Theta-plane. The system is composed of a 1.05 kg stepper motor from Pololu and a stepper motor driver from SparkFun. All components shall be tested and assembled to take into account thermal expansion/contraction due to varying temperatures following launch. The motor shall be a stepper motor with a small minimum step angle. The motor will have 200 steps per revolution, will have a holding torque of 19 kg-cm, and will use a stepper motor driver to achieve 9600 steps per revolution for increased precision. This ensures that the motor is accurate in its rotation and stepper motors provide enough torque and control. The imaging system, along with photodiode arrays, will be mounted to the motor. If the motor by itself is not powerful enough to turn the imaging system, a gear assembly with a 3 to 1 gear ratio will be added, which will increase the torque and the number of steps per revolution. The gear assembly would consist of two gears on a flat plate attached with a tensioned chain. The gear assembly would also act as a speed reducer for the motor so that maximum accuracy is maintained and motor torque is not compromised.

4.2.2.2 Phi-Plane (ϕ) Motor System

The Phi-Plane motor system orients the direction of the imaging system in the Phi-plane. This system is composed of a 1.05 kg stepper motor from Pololu and a stepper motor driver from SparkFun attached directly to the axis of Phi-Plane Array. The Phi motor will have a 19 kg-cm holding torque and 200 steps per revolution and will use a stepper motor driver to achieve 9600 steps per revolution, which equates to 0.1125 steps per degree.

4.2.3 Procedure of Operation

The orientation of the imaging system shall work in two steps. ADCS shall work by processing the raw data from the arrays and ADCS camera, taking into account each photodiode reading before choosing the photodiode exposed to the most intense light. The ADCS system shall then rotate in the direction with the most intense light readings. The ADCS shall repeat this step until the readings of each photodiode in the main pair are equal to each other, indicating that the Sun is in the center of the field of view. Because the sunlight reflected off of the balloon can cause the photodiodes on the Phi-axis to give false readings, the ADCS system shall utilize the ADCS camera to confirm that the Sun is in the center of the field of view. Images with the higher resolution Science camera shall only be taken once orientation of the camera housing is complete and the Sun is in the center of the field of view. The orientation of the imaging system shall work in two steps.

1. Macro tracking with photodiodes:
   a. The control system shall receive data from the Theta-Plane array and determine which of the two primary photodiodes is receiving the most light. Then, the control system shall send the necessary commands to the Theta-Plane Motor System and orient the imaging system along the previously computed direction of most light, thus repositioning the system along the Theta-plane. This procedure is repeated until both primary photodiodes record equal readings, indicating that the Sun is oriented in the center of the Theta-Plane.
   b. The control system receives data from the Phi-Plane array and the above process is repeated to position the system in the Phi-Plane. This procedure is repeated until both primary photodiodes record equal readings, indicating that the Sun is oriented in the center of the Phi-Plane.
2. Micro tracking with ADCS camera:
   a. Due to unintended light pollution from surrounding objects, the photodiodes may record faulty readings indicating that the Sun is in the center of the field of view when it is not. Because the ADCS camera is not vulnerable to reflected sunlight, it shall be used to micro track the Sun once the Sun is within the field of view of the camera.
   b. The flight computer will analyze images from the ADCS camera, locating the center of the Sun, and send commands to the motors that will place the Sun in the center of its, and the Science camera's, field of view.

4.2.4 ADCS Test Procedures:

The solar position determination system shall be tested by positioning an intense light source simulating the Sun in different predetermined positions in a dark room. The responses from the photodiodes and the ADCS camera shall be recorded and checked for accuracy. The controls shall be corrected and restructured as needed to ensure minimum error. A smaller light source shall be placed directly above the determination system to simulate the reflected sunlight from the balloon. Again the responses from the photodiodes and the ADCS camera shall be recorded and checked for accuracy, and the controls shall be restructured as needed. In addition to testing the ADCS indoors, The ADCS shall be tested outdoors to ensure that it can accurately track the Sun as the main light source.

To test the functionality of the ADCS, it will be tested under various conditions. To test long term tracking of the Sun, the completed payload will be set outside on a sunny day to monitor the functionality of the tracking system. To test the system's ability to maintain the Sun in its field of view HELIOS III will be rotated at a rate comparable to the expected rate of rotation of the HASP platform. To test the system's ability to regain the Sun HELIOS III gain a lock, then the structure will be repositioned so the system is facing away from the Sun. To test the ability of the ADCS camera to maintain a lock on the Sun HELIOS III will be allowed to lock on to the Sun and then the photodiodes will be coved individual. All of these tests mimic expected light or movement conditions during flight. Covering the photodiode simulates a condition that last year's team encountered where the cameras were pointing at the Sun but the diodes were shaded by the HASP platform. Pointing the system away from the Sun and having it reacquire a lock simulates post-blackout conditions if the cameras are pointed in the wrong direction when the payload is turned back on.

The rotation and positioning system shall be tested in parallel with the solar position determination system. The accuracy with which the motors are able to position the SWIS shall be checked. In order to simulate the random rotational movement of the HASP platform, the ADCS shall be placed on a rotating platform and spun while its rotational speeds are recorded with a tachometer. The photodiode readings from each of the arrays of the rotating ADCS will then be compared with the corresponding readings of static photodiode arrays pointing at the Sun. If the readings are equal within a margin of error, then the ADCS has accomplished its objective. The same process shall be simulated to test the performance of the ADCS camera under these conditions.

The ADCS system shall be subjected to extreme thermal conditions, simulating the thermal and environmental conditions that it shall operate in at high altitudes. The ADCS shall record accuracy of the solar position determination system and the repositioning system separately and as a whole.

4.3 Structural Design:

HELIOS III's assembly consists of two major substructures; the base housing structure, and the SWIS housing structure. Both substructures shall be machined with aluminum plates and shall use a truss pattern to minimize the weight. This segment will be thermally isolated, and will be keep a thermal barrier between the heat-producing processing components and the heat-sensitive imaging system positioned in the second substructure. A Truss structure shall be used to reduce the overall weight. The base structure shall be thermally isolated from the SWIS housing to prevent distortions of the thermally sensitive imaging system. HELIOS III shall address the human factors involved in assembling the structure. HELIOS II failed to take this into consideration, and had difficulties securing structure to base plate with screws. The base structure, 38 cm x 29 cm x 8.86 cm, shall contain the C&DH system, EPS, Theta-axis motor, and potentially a chain system. The base structure shall be thermally isolated from the SWIS housing to prevent distortions of the thermally sensitive imaging system.

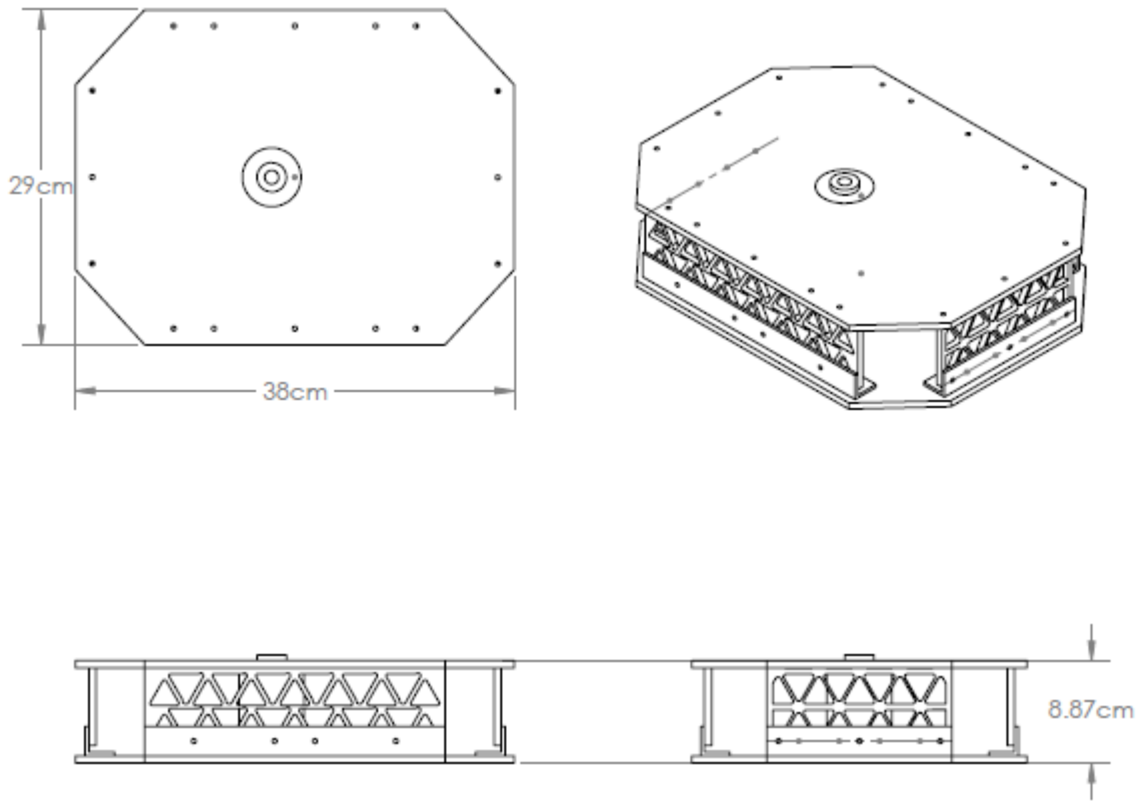


Figure 4.6 Base Structure Design

Appropriate considerations shall be taken to guarantee that the structure will stay sound despite the effects of thermal expansion. The SWIS housing structure shall be located on top of the base structure. It shall house the SWIS, Phi and Theta photodiode arrays, and Phi-axis motor. The Theta photodiode array shall be located above the camera housing and shall be centered above the SWIS structure. The Phi photodiode array shall be attached to the side of the SWIS structure, with the center of the photodiode array lined with the center of the camera housing. Both photodiode arrays shall be manufactured with a 3D printer at the University of Colorado at Boulder's Integrated Teaching and Learning Program Laboratories and shall be an 'L' shaped configuration with dimensions of 11cm x 4 cm x 4.50 cm (Figure 4.3 Photodiode Housing). The Phi-axis motor shall be located on the opposite side of the Phi photodiode array. The total height of HELIOS III shall be 29.94 cm.

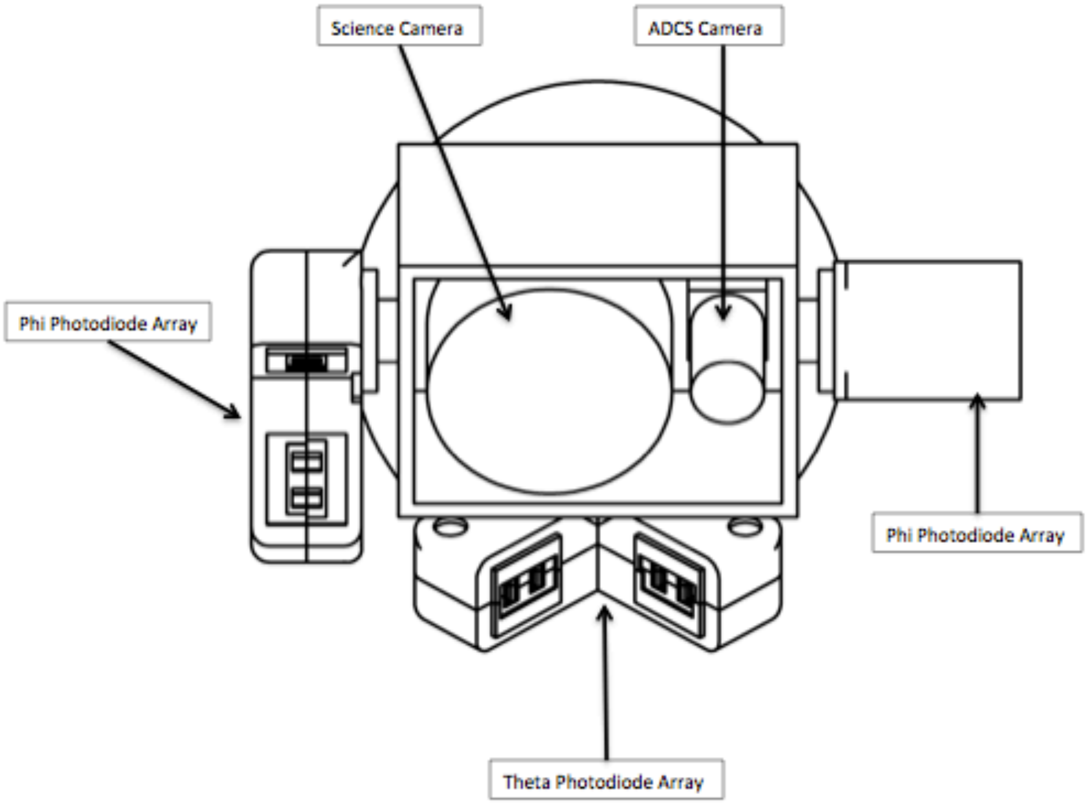


Figure 4.7 Camera Swing Design

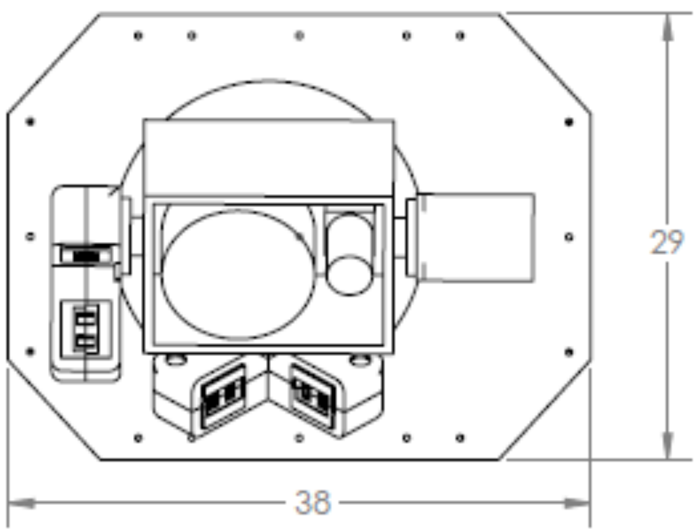


Figure 4.8 Top-down View of Base and Camera Swing

4.3.1 Structure Integration

The baseplate will be connected to the four side plates. Next the base plate will be attached to the HASP mounting plate through two sets of screws. Finally the top plate will be attached to the base structure and the SWIS housing will be secured above the base. Both the DVB9 and the EDAC connectors will be placed in the established positions ready to be interfaced on the bottom with the corresponding plug.

4.4 Command and Data Handling

The C&DH system onboard of HELIOS III shall include three main components: A flight computer, a microcontroller, and a data storage system. HELIOS III's flight computer shall run a modified, low resource, Linux kernel. The flight computer will handle all ADCS calculations, send commands to the motors, and capture all images. In addition, the flight computer shall control ground communication, measure system health, and handle and store data. An Arduino Mega microcontroller shall be used to collect environmental data of the flight, provide a reference for any anomalies that may occur, monitor power draw of all electronics, and be capable of turning off power to any system that draws more power than the it is allotted. The last element of the C&DH system shall be a solid-state drive that shall be used for the storage of all flight sensor data and captured images. The flight computer shall interface to the HASP platform's downlink/uplink communication via the DB9 connector to allow ground control of the payload and the transmission of environmental data. See the Functional diagram for EPS and C&DH (pg.23) for a visual representation of the system.

4.5 Electric Power System

HELIOS III shall receive 30 Volts DC from the HASP platform. Four linear step-down regulators shall be used to initially reduce power. Next linear regulators shall be used to further step down the power to what is required for each subsystem. HELIOS III plans to replace the buck converters on last year's design, with Linear Technology's Step-Down switching regulators. These components should be more reliable and reduce the risk of failures similar to those of HELIOS II from occurring. HELIOS III will use a larger surface area of copper on heat sinks in order to maximize heat transfer. Current sensors on each connection shall help the HELIOS III team monitor and analyze the system to prevent failures from occurring. Additionally, remote digital relay solenoid switches shall be used to cut power from any line if necessary. Switches will be controlled by commands from the ground station and relayed through the Raspberry Pi to the Arduino Mega.

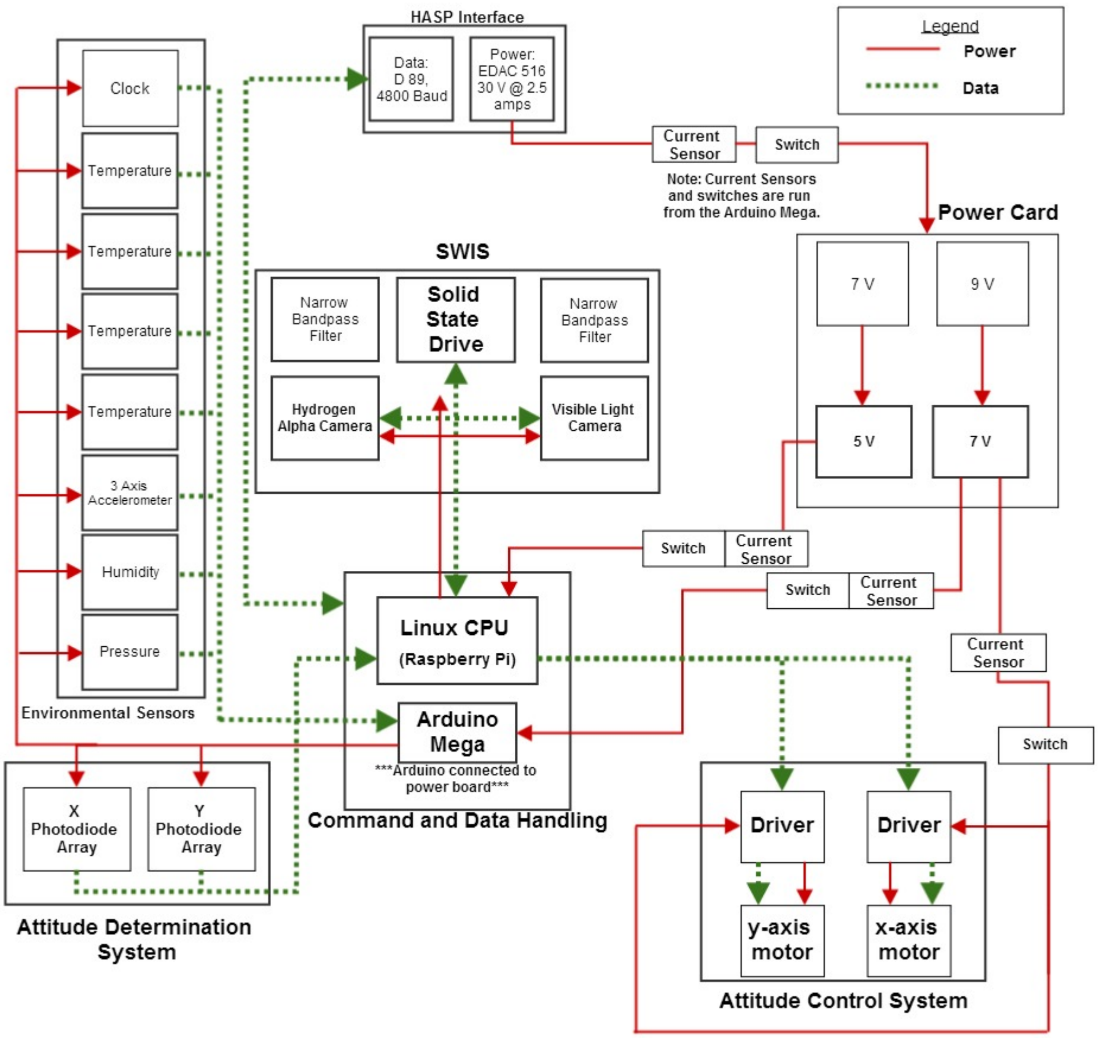


Figure 4.9 Functional Block Diagram

The schematic (Figure 4.10) below represents the mother schematic of the EPS board. It shows that the power board will receive 30V in, and then separate power to four lines. Each line of power will use a linear switch-down regulator, and a linear regulator to achieve the correct amount of power. Three lines will output 7V, and one will output 5V. Current sensors will then monitor the current achieved by each line. Finally, separate connectors are used for each line to output voltage to other systems

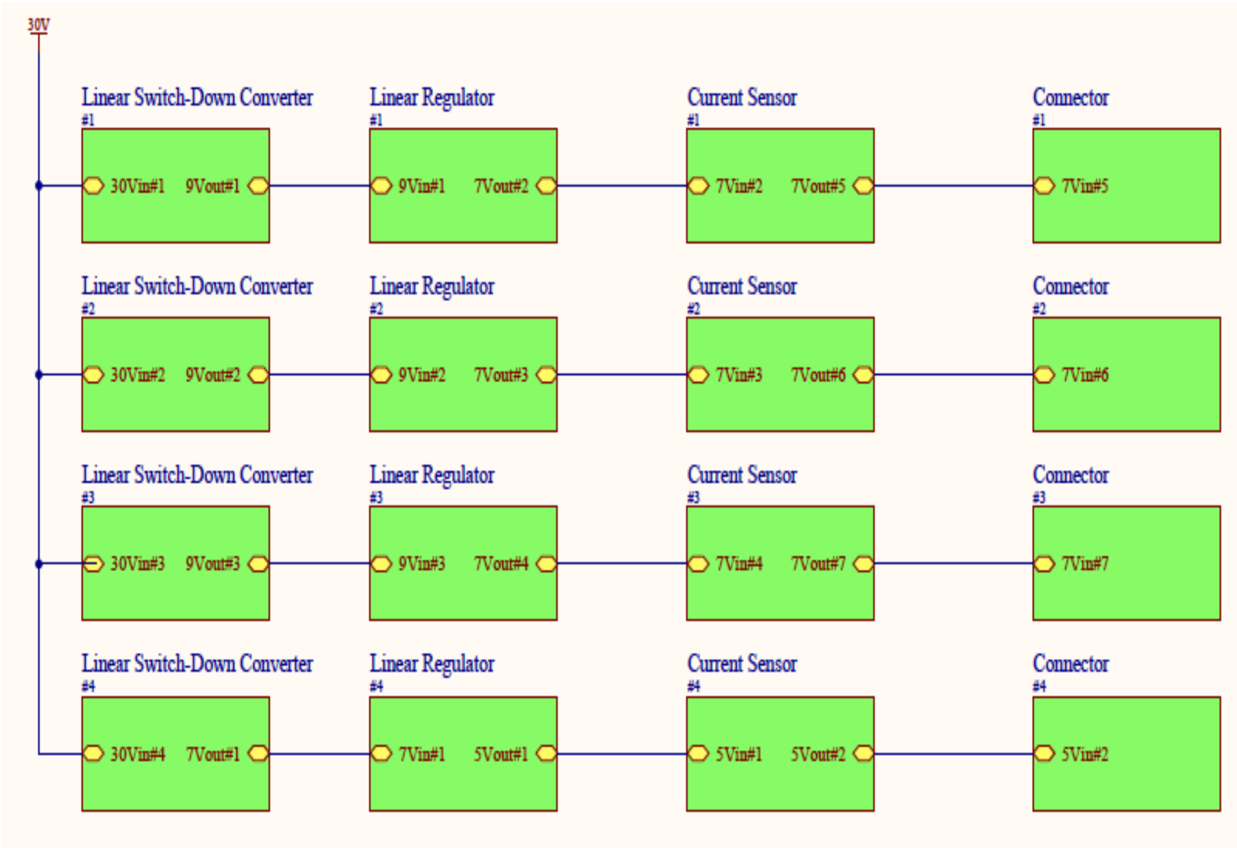


Figure 4.10 Power Circuit Diagram

4.5.1 Power Budget

The following table depicts the estimated power required for each HELIOS III system during flight, as well as total power required for the entire payload at any given time. The power values displayed were calculated by using the maximum current and voltage values available for every component. HELIOS III will only use about 20% of the 75-Watt power output delivered by the HASP platform.

Table 4-1 Power Budget

INSTRUMENT	VOLTAGE (V)	CURRENT (A)	POWER (W)
ARDUINO MEGA	7	0.5	3.5
CPU (RASPBERRY PI)	5	0.5	2.5
CAMERAS	5	0.5	2.5
SOLID STATE DRIVE	5	0.5	2.5
MOTOR DRIVERS	7	0.5	3.5
TOTAL MAX POWER DRAW			14.5
MAX ENERGY DRAW (WHR)			290

4.6 THERMAL

Part of HELIOS III's success depends on maintaining temperature within operational range of all systems. The heat given off from the processing unit, as well as the voltage regulators shall provide ample heating to the internal systems. The internal temperature may rise above operational limits, potentially leading to failure of internal systems. HASP shall reach an altitude of approximately 36,000 meters. At this altitude, the ambient pressure shall make convection impossible. Based on research, the hottest components in the system will be the motors, motor drivers, and CPU. In order to prevent failure due to overheating, heat sinks shall be applied to the linear regulators using thermal epoxy. Copper wires will be used to heat sink the components. The HELIOS III team is working with Dr. Guzik to investigate ways of using the heat sinks. A potential solution being investigated is applying the heat sinks to the hardware used to attach the payload to the HASP platform. In this way, the applied heat sinks would directly conduct the thermal energy from the payload to the HASP platform, at which point it would be radiated into the atmosphere. The structure would consist of a solid aluminum base plate so that the heat could slowly drain through the screw heads connecting the base plate to the HASP platform. Heat sinks avoid reliance upon complex fluid cooling systems and shall function in a near-space environment. Therefore, the payload would utilize the structure of the HASP platform to store and then distribute excess heat away from the processing system. In addition, the structure shall be painted white to reflect as much heat and light as possible. Finally, because last year's HELIOS team lost communication with the payload when it exceed 60 °C and because the maximum operating temperature for the Raspberry Pi is 70 °C , all systems shall be shut off if the internal temperature exceeds 60 °C to prevent the systems from being damaged by the heat. A test will be completed to test these components, simulating flight conditions while running the equipment to check for any over or under heating in the system. As an added precaution, hardware has and will be selected based on operational thermal ranges. Thermal management has been taken into account during the design of the platforms structure.

5 MANAGEMENT

HELIOS III consists of 10 members. Each member shall be in charge of a subsystem based on interest and/or experience with the subsystem. HELIOS III shall work with faculty advisors and members of the HELIOS II team to ensure the successful design and construction of the payload. The HELIOS II advisors shall work closely with the HELIOS III team in the subsystems of their expertise in order to give their knowledge and experienced gained from the 2013 HASP mission. The member of HELIOS III and leads are subject to change. The current members affiliation is based on proposal writing team, while the final team selection will occur if HELIOS III is awarded a seat.

5.1 Team Organization

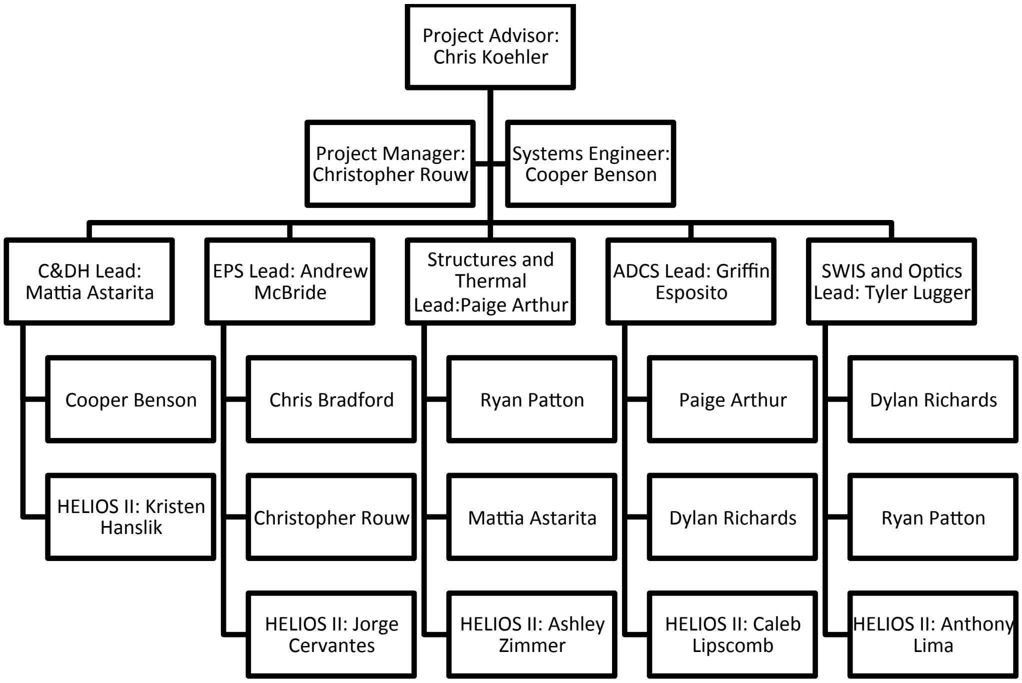


Figure 5.1 Organization Chart

Table 5-1 Team Leader Contact Information

Name	Affiliation	Email	Phone Number
Chris Koehler	Project Advisor	Koehler@colorado.edu	303-492-3141
Dr. James Green	Faculty Advisor	James.green@colorado.edu	N/A
Cooper Benson	Systems Engineer	Cooper.Benson@colorado.edu	719-649-9832
Christopher Rouw	Project Manager	Christopher.Rouw@colorado.edu	320-260-3189
Paige Arthur	Structures & Thermal Lead	Paar5780@colorado.edu	303-957-7360
Andrew McBride	EPS Lead	Andrew.McBride@colorado.edu	307-251-7659
Tyler Lugger	Optics Lead	Tyler.Lugger@colorado.edu	720-231-3549
Griffin Esposito	ADCS Lead	Griffin.Esposito@colorado.edu	630-542-5586
Dylan Richards	SWIS Lead	Dyri3017@colorado.edu	N/A

5.2 Scheduling

In addition to these scheduled meetings and conferences below, HELIOS III shall meet a minimum of once a week to accomplish project tasks and meet with HELIOS III's project advisor, Chris Koehler. During these meetings, team members shall discuss the current state of the project, and each system lead shall submit progress reports to the Systems Engineer and Project Manager. Each sub-section shall meet at their discretion and work on their system tasks. Reviews will be held with both HELIOS III's faculty and science advisors plus current and past COSGC students. A more detailed schedule is currently in development and incorporates lessons learned from HELIOS I and II.

	2013		2014												
MileStones	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Notes
Team Formed	X														Form proposal writing team
Sumbit Proposal		X													Ensure all of last years problems are adressed
Payloads Selected			X												
Submit Selection Response															Adress an comments to the proposal
Preliminary Design Review															
Critical Desgin Review			X												With in two weeks of selection present CDR to Space Grant and project affiliates
Preliminart PSIP Due						X									Payload Specification Integration Plan
Finalize EPS							X								
Finalize SWIS							X								Cameras and baffing system calibrated
Finalize ADCS							X								ADCS camera and photodiodes calibrated and tested
Finalize Structure							X								All machining and structural interface completed
Final PSIP Due								X							Payload Specification Integration Plan
FLOP Due									X						Flight Operations Plan
Inhouse Vaccum Testing									X						Test all subsystems in Space Grants vaccum chamber
Thermal and Vaccum Testing at CSBF										X					Test at Palestine Texas
Intergration at CSBF										X					
HASP Flight Preperation										X					
Target Flight Ready										X					
Target Launch Data											X				
Flight Operations											X				
Recovery											X				
Final Flight/ Science Report														X	

Figure 5.2 HELIOS III Schedule

6 WEIGHT BUDGET

HELIOS III will maintain a budget with value, cost, item name and number, weight, and distributor. The project manager will be responsible for overseeing the budget and the raising of all funds necessary to ensure a successful mission of HELIOS III. The Budget below is a preliminary budget based on estimates of hardware expected to be used by HELIOS III. The budget will be continuously updated to reflect an accurate account of parts, weight, and cost.

Table 6-1 Weight Budget

ITEM NAME AND NUMBER	DISTRIBUTOR	WEIGHT (G)	QUANTITY	TOTAL WEIGHT (G)
MOTORS	Pololu	1050	2	2100
UI-1240SE-M-GL ADCS CAMERA (#AB.0010.1.46500.23)	IDS	65.0	1	65.0
UI-1480SE-M-GL	IDS	65.0	1	65.0

SCIENCE CAMERA (#AB.0010.1.33600.23)				
RASPBERRY PI MODEL B (#43W5302)	Element14	45.0	1	45.0
ARDUINO MEGA		35.0	1	35.0
EPS BOARD		1000.0		1000.0
STRUCTURE		7000.0	1	7000.0
TOTAL				10310.0

7 INTEGRATION AND LAUNCH

Upon integration of HELIOS III into the HASP platform, all System Leads, the Systems Engineer, and the Project Manager shall ensure proper integration procedure is followed. A comprehensive checklist shall be used to confirm a successful integration of the HELIOS III payload. The System's Engineer shall test all communication processes and equipment throughout integration to assure proper function. HELIOS III plans to keep payload attached to HASP mounting plate after integration. The following is a detailed integration plan HELIOS III will follow at CBF in Palestine, TX.

1. Payload does not exceed mechanical constraints of 20 kg, and 38x30 cm by 30cm tall
2. Payload base fits within the 15.875x12.375 minus 3.981x2.9375x26875 corners
3. Ensure HELIOS III Payload is physically attached to HASP Platform
4. Ensure the PVC plate is secured to HASP Platform
5. Ensure HELIOS III payload is secured to PVC plate.
6. Ensure all electrical wiring and digital communication lines are properly connected to all systems
7. Ensure HASP wiring hookups are correct.
   i. Check and confirm Serial hookup
   ii. Check and confirm EDAC hookup
8. ADCS
   i. Ensure Motors connected to the flight computer
   ii. Ensure Photodiodes connected to flight computer
9. Optics
   i. Cameras connected to the flight computer
10. C&DH
    i. Microcontroller connected to EPS power board
    ii. The flight computer connected to EPS power board
    iii. All environmental sensors connected to C&DH microcontroller
    iv. All Serial communication lines connected to DB9 connecter
11. EPS hookup
    i. Ensure EPS is connected to HASP power line through EDAC 516 interface
    ii. Ensure all internal wiring is properly secured
12. Thermal
    i. Ensure all heat sinks are properly attached to structure
13. Verify functionality of individual systems:
14. Structures and Thermal
    i. Ensure all structural components are securely attached to the HASP platform

   ii. Ensure all heat sinks are securely attached to their thermal dump surfaces

15. EPS
    i. Ensure power from HASP platform is being received from EDAC 516 interface
    ii. Ensure EPS is distributing power to all systems.
    iii. Ensure power draw does not exceed 30V at 2.5 Amps DC
16. C&DH
    i. Ensure serial communication through DB9 connecter is functioning
    ii. Confirm serial communication is at 4800 baud
    iii. Ensure C&DH is communicating with all other subsystems
    iv. Check the functionality of the EDAC analog command channels (K,L and M,R)
    v. Send command bit to each individual system.
    vi. Ensure C&DH is receiving H&S from all systems and environmental sensors
17. Optical
    i. Ensure Cameras are receiving power from the flight computer
    ii. Ensure Cameras are communicating with the flight computer
    iii. Take test image with each camera
18. ADCS
    i. Ensure ADCS microcontroller is communicating with the flight computer
    ii. Ensure ADCS is getting readings from photodiodes
    iii. Test motor functionality
    iv. Test ADCS rotation and pointing by shining a light at the photodiode array
19. Verify entire payload functionality.
    i. Command C&DH to power on/off payload
20. Command C&DH give Health and Status to ground station.
21. Ensure communication between C&DH, EPS, ADCS, and Optical system
    i. C&DH command EPS to power on/off each individual system
    ii. C&DH command ADCS to begin actively tracking the Sun
    iii. ADCS command cameras to take image
    iv. Ensure Image captured is transmitted to the flight computer and is stored in solid-state drive.
22. Final Mission Simulation
    i. Activate payload using serial command from ground station

7.1 Launch Procedures

The following is an approximation of flight times, altitudes, and events. The leftmost column are estimated times in the hour-minute-second format. In the rows associated with each time are estimated altitudes, flight events, and system directives. The mission outline works on the assumption that the float time shall have 10 +/- 4 hours of sun visibility. The Project Manager is responsible for ensuring that all of the flight procedures are properly followed and completed. The team leads of each subsystem shall be responsible for ensuring that their respective subsystems successfully undergo integration into the HASP platform. During the flight the C&DH lead shall be responsible for controlling all discrete commands to the HELIOS III payload on the HASP Platform.

Table 7-1 Launch Schedule

EST. TIME	EST. ALT (M)	FLIGHT EVENT	SYSTEM EVENT	EVENT SUB-TASKS
T – 1 DAY	0	N/A	Pre-Launch Check	Verify all systems
T – 1 DAY	0	HASP Integration	HASP Integration	
T – 01:00:00	0	N/A	Flight Line Setup	
T = 00:00:00	0	Launch	N/A	
T + 01:00:00	36,576	Max Altitude	All systems on	
T + 01:30:00	36,576	Float	Begin ADCS solar location loop	Record ADCS attitudes and behavior
T + 01:45:00	36,576	Float	Enable SWIS	Collect images
T + 20:00:00+	36,576	Before Descent	Disable Systems, Power Down	
T + 20:00:00+	36,576	Begin Descent		
T + 20:00:00+	0	Landing		

8 Conclusion

The goal of HELIOS III is to determine the feasibility of using a high altitude balloon platform as a solar observation platform. HELIOS III shall show that it is possible to take high quality images of the Sun in the Hydrogen Alpha wavelength using a high altitude balloon platform. In addition, HELIOS III shall fly two different camera barrels, one with a high resolution and a small field of view and a second with a large field of view and a lower resolution. HELIOS III shall compare the images taken by HELIOS III with test images from a ground station as well as images taken using orbital telescopes to see if the balloon observation platform can produce comparable images of the Sun. Should the HELIOS III mission prove successful, high altitude balloons could offer much greater access to high quality solar observation by providing a cheaper alternative to multi-million dollar orbital solar observatories, and by eliminating the atmospheric interference experienced by ground-based solar observatories.

9 Appendix

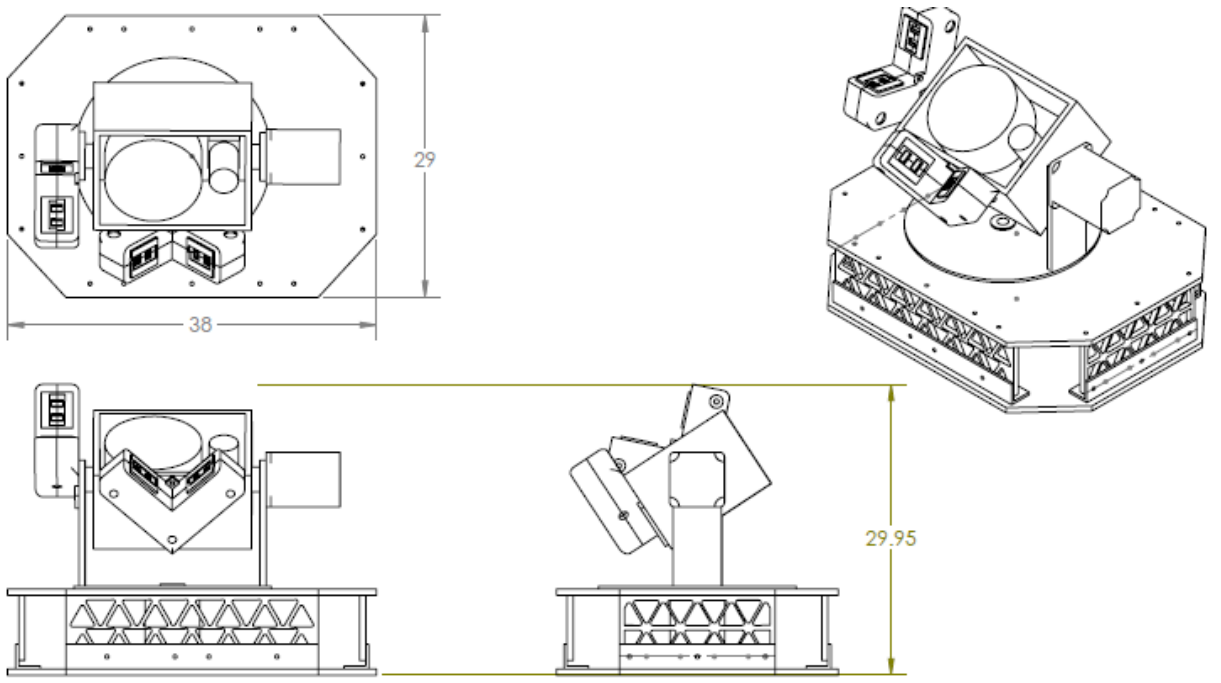


Figure 9.1 Full Design

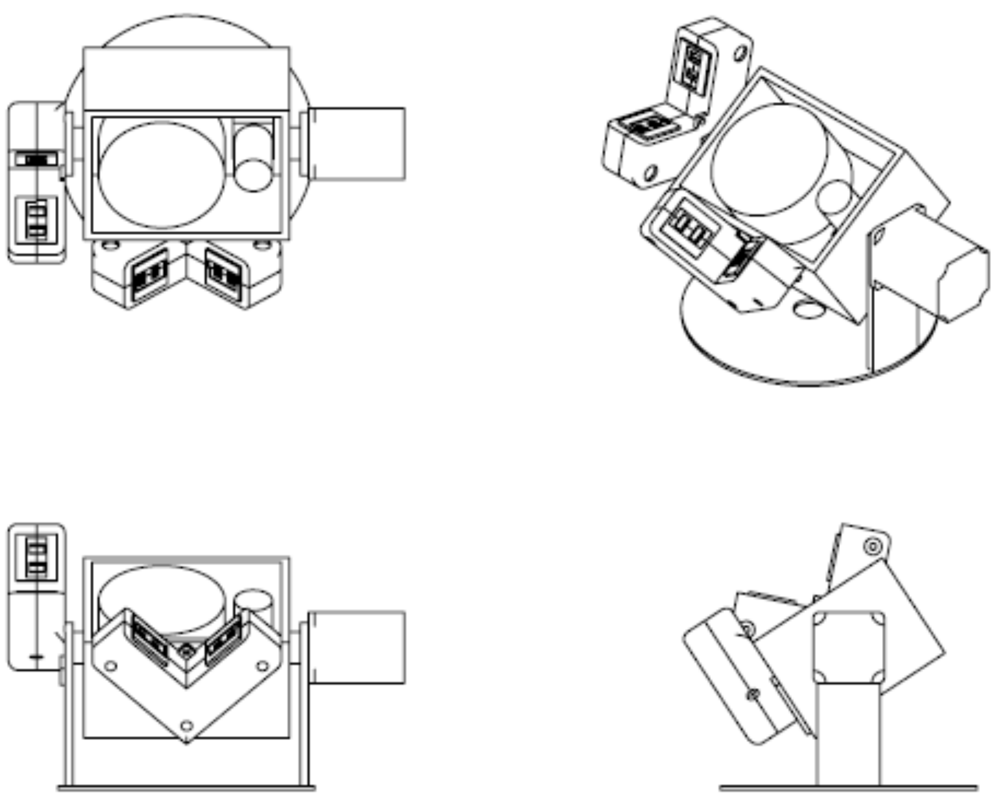


Figure 9.2 Camera Swing Design

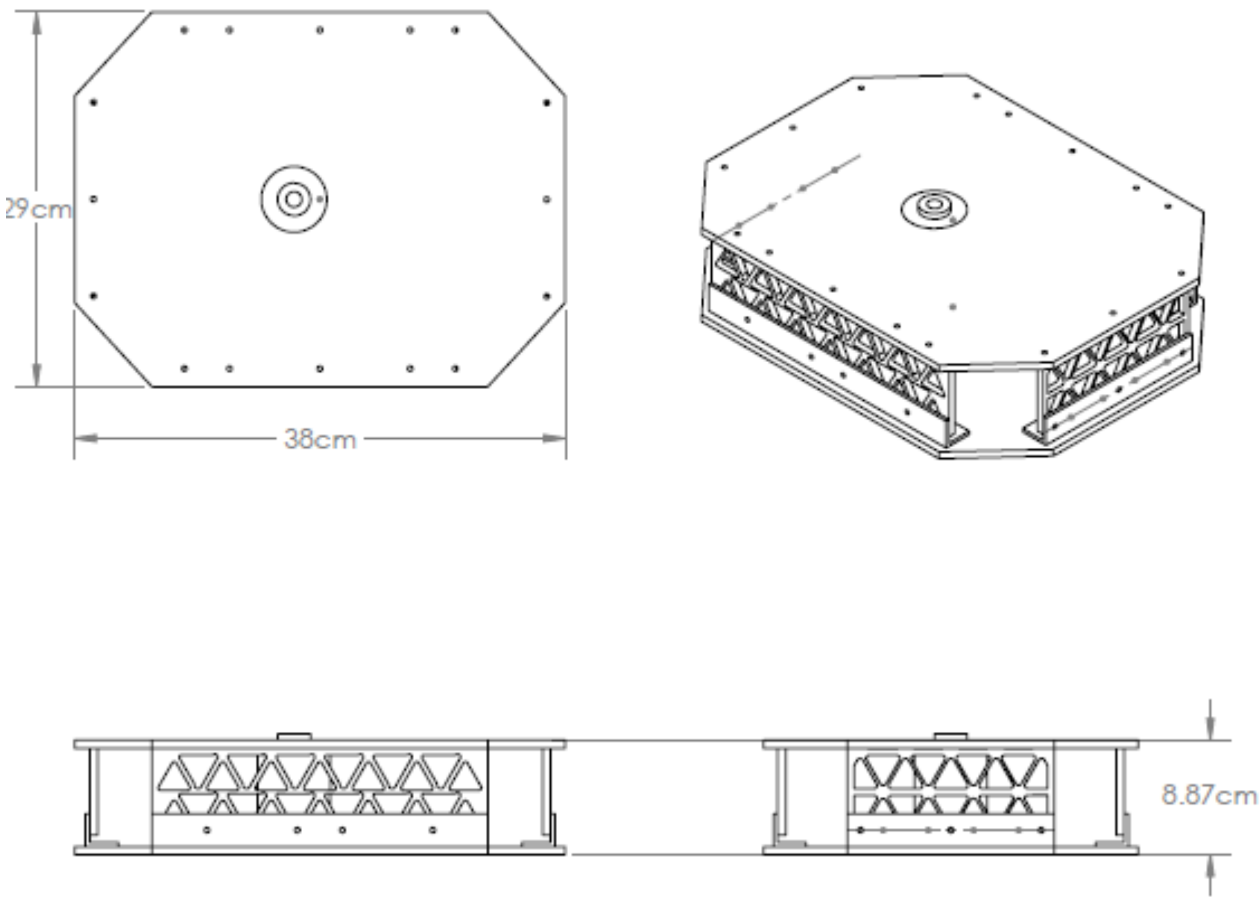


Figure 9.3 Base Design