# HASP Student Payload Application for 2015

Payload Title:
HELIOS IV

| | | |
|---|---|---|
| Payload Class: (check one)<br>☐ Small ■ Large | Institution:<br>University of Colorado - Boulder | Submit Date:<br>December 15, 2014 |

Project Abstract

HELIOS IV shall observe the Sun in Hydrogen-Alpha wavelength. Observations in this wavelength from 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, 2013, and 2014 HASP teams’ missions, HELIOS I, HELIOS II, and HELIOS III. HELIOS IV is attempting to re-fly the mission to overcome the technical issues that hindered the HELIOS III team as well as improve upon the science results. HELIOS IV will focus on improving the Optics, Attitude Determination and Control System, and Electrical Power System of HELIOS III. HELIOS IV 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 IV payload, a large payload seat is necessary for this mission.

| | |
|---|---|
| Team Name:<br>HELIOS IV | Team or Project Website:<br>http://spacegrant.colorado.edu/boulderstudents/boulderprojects/hasp-home |

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# Hydrogen-Alpha Exploration with Light Intensity Observation Systems IV

## Proposal

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## Nomenclature

| | |
|---|---|
| ADCS | Attitude Control and Determination System |
| BOM | Bill of Materials |
| CDH | Command and Data Handling |
| COSGC | Colorado Space Grant Consortium |
| EPS | Electronic Power System |
| FBD | Functional Block Diagram |
| GPIO | General Purpose Input and Output |
| H-alpha | Hydrogen alpha |
| HASP | High Altitude Student Platform |
| HELIOS | Hydrogen-Alpha Exploration with Light Intensity Observation Systems |
| MLI | Multi-Layer Insulation |

# Contents

# I. Mission Overview

## A. Mission Objective

HELIOS IV (Hydrogen-Alpha Exploration with Light Intensity Observation System) shall prove the viability of solar observation on a high altitude balloon platform. This shall be achieved by designing and constructing an optics system to capture images of the sun in near hydrogen alpha wavelength using an attitude determination and control system (ADCS) to locate the sun and orient the optics system towards the sun on-board a HASP flight.

Mission Objectives:

1. Design an implement an ADCS system to locate the sun the in sky and orient the optics system.
2. Observe and capture images of the sun in near hydrogen alpha wavelength with the optics system.
3. Design a high altitude balloon solar observation platform for a COSGC-sponsored HASP flight.

## B. 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 earths 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 and extinction 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 causing 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 fix the problems found in HELIOS I. This 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 encountered by the HELIOS II mission involved several systems overheating, the ADCS system being confused by reflections off the balloon, and reliability issues in the Command and Data Handling system. Last year, HELIOS III flew with the same mission and experienced much greater success, as they payload captured over 75 partial images of the sun. However, due to power and balancing issues encountered immediately before flight, only movement in azimuth was achieved. Furthermore, only one camera was able to be flown, instead of the planned two cameras.

The HELIOS IV team plans to correct the issues encountered by HELIOS III by:

1. Utilizing a new motor driver that does not limit current to the motor so that the motor has enough power to move the upper housing.
2. Ensuring that the system is sufficiently balanced such that the motor can easily turn it.
3. Ensuring that both cameras can function simultaneously before flight.

4. Designing a more organized power board with only one ground plane.

Unlike previous iterations of HELIOS, the HELIOS IV team is composed primarily of members who worked on the HELIOS III mission. As such, HELIOS IV is meant to be an improvement upon HELIOS III. Since the HELIOS III payload was largelysuccessfully in proving the viability of solar observation on a high altitude balloon platform, HELIOS IV aims to only make those changes which would have made HELIOS III entirely successful.

### C. Photometry

The HELIOS IV payload shall capture images of the sun in the hydrogen-alpha (656.3 nm) wavelength and shall maximize image quality. H-Alpha filters allow the camera to detect only red light at a specific wavelength of 656.3 nm. These wavelengths are frequently emitted from the chromosphere of the sun 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 and overall light intensity from the photosphere typically drown them out, becoming ‘etiolated’ in unfiltered cameras.

Hydrogen-alpha is a useful wavelength for solar imagery, as it allows the observer to see granulation, sunspots, and solar flares. Hydrogen-alpha exists in two layers of the sun: the photosphere and chromosphere. Both layers exist in the suns atmosphere, with the photosphere being the lowest level and the chromosphere being the mid layer of the atmosphere, just above the photosphere. Hydrogen-alpha gives a reddish color to the chromosphere, but this is generally not observable during normal conditions as the photosphere is too bright. The majority of solar features, such as granules and sunspots, are only observable in the photosphere. Hydrogen-alpha, however, allows the viewer to observe solar features through the photosphere, thus allowing a greater analysis of solar activity in the sun.

HELIOS III was able to capture multiple partial images of the sun during its flight, but the images were too saturated to observe surface features. HELIOS IV hopes to capture the entire disk of the sun, as well as being able to view sunspots.

### D. Principle of Operations

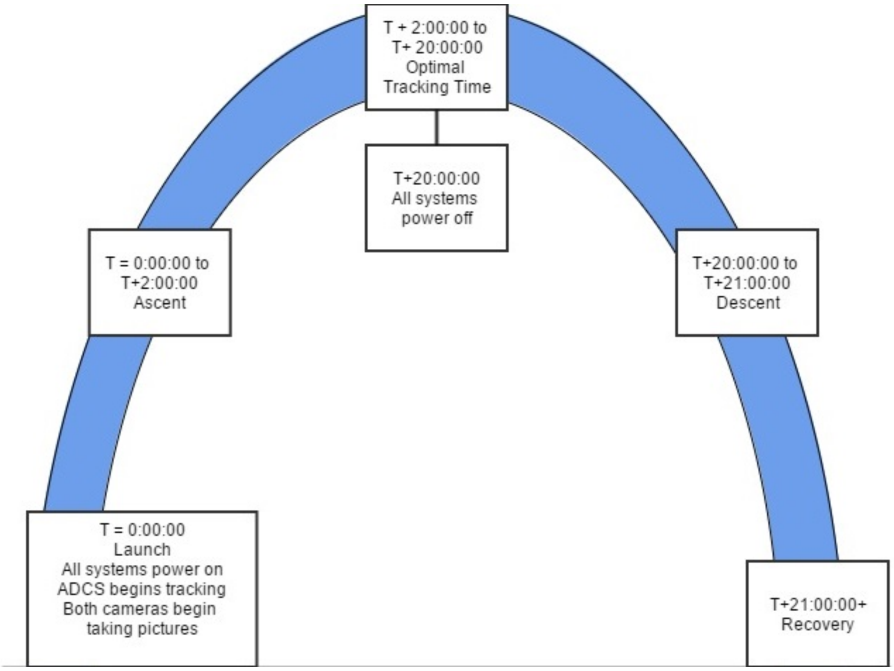


Figure 1: Principle of Operations

# II. Mission Requirements

| Level | Requirement | Derived |
|---|---|---|
| 0 | Hydrogen-Alpha Exploration with Light Intensity Observation System (HELIOS) IV shall designed and constructed with an optics system for capturing images of the sun in the hydrogen alpha wavelength and utilizing an ADCS to locate the sun and orient the optics system towards the sun on-board a HASP flight | |

| Level | Requirement | Derived |
|---|---|---|
| 0.1 | Observe and capture images of the sun in the hydrogen alpha wavelength | 0 |
| 0.2 | Design and implement an ADCS to locate the sun and orient the optics system toward the sun | 0 |
| 0.3 | Design a high altitude balloon solar observation platform for a COSGC-sponsored HASP flight | 0 |

| Level | Requirement | Derived |
|---|---|---|
| 0.1.1 | The optics system shall implement an Hydrogen-Alpha filter allowing imaging of 656.3 nm wavelengths | 0.1 |
| 0.1.2 | The optics system shall implement a camera capable of gathering high resolution hydrogen alpha images | 0.1 |
| 0.1.3 | The CDH system shall allow for storage of captured images | 0.1 |
| 0.1.4 | One barrel of the optics system shall have a large field of view with low magnification | 0.1 |
| 0.1.5 | One barrel of the optics system shall have a small field of view with high magnification | 0.1 |
| 0.1.6 | The optics system shall be insulated and isolated from all other systems' thermal footprint | 0.1 |
| 0.1.7 | The optics system cameras shall be compatible with the main CPU. | 0.1 |

| Level | Requirement | Derived |
|---|---|---|
| 0.2.1 | ADCS shall monitor changes of the sun's orientation along the elevation and azimuth | 0.2 |
| 0.2.2 | ADCS shall use motors to orient the optics system in the direction of the sun | 0.2 |
| 0.2.3 | ADCS shall be capable maintaining the sun within the field of view of the optics system | 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 IV shall comply with all HASP requirements outlined by the Call for Proposals and other LaSPACE documents | 0.3 |
| 0.3.2 | HELIOS IV shall comply with all budget and schedule constraints dictated by COSGC and HASP | 0.3 |
| 0.3.3 | HELIOS IV shall maintain a proper operational environment throughout flight | 0.3 |

| Level | Requirement | Derived |
|---|---|---|
| 0.1.4.1 | The optics system shall have one camera with a field of view no less than 15° x 10° | 0.1.4 |

| Level | Requirement | Derived |
|---|---|---|
| 0.1.5.1 | The optics system shall have one camera with a field of view of 1.5° x 1° | 0.1.5 |
| 0.1.5.2 | The optics system shall have one camera with a resolution of greater than 1600 pixels x 1200 pixels | 0.1.5 |

| Level | Requirement | Derived |
|---|---|---|
| 0.1.6.1 | The optics system shall remain below 60 °C throughout the flight | 0.1.6 |

| Level | Requirement | Derived |
|---|---|---|
| 0.2.1.1 | ADCS shall record sun’s orientation in elevation every seventh of a second | 0.2.1 |
| 0.2.1.2 | ADCS shall record sun’s orientation in azimuth every seventh of a second | 0.2.1 |

| Level | Requirement | Derived |
|---|---|---|
| 0.2.2.1 | ADCS motors shall be capable of rotating the optics system by 3 °/s | 0.2.2 |

| Level | Requirement | Derived |
|---|---|---|
| 0.2.3.1 | ADCS elevation motor shall have a precision of at least 0.2° per step | 0.2.3 |
| 0.2.3.2 | ADCS azimuth motor shall have a precision of at least 0.06° per step | 0.2.3 |

| Level | Requirement | Derived |
|---|---|---|
| 0.2.4.1 | Azimuth and elevation motors shall remain below 60 °C 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 IV system power and analog downlink channels | 0.3.1 |
| 0.3.1.4 | Payload shall not draw more than +30 VDC or 2.5 A and shall split the provided +30 VDC to voltages necessary to operate payload | 0.3.1 |
| 0.3.1.5 | Payload shall allow serial downlink functioning at 4800 baud | 0.3.1 |
| 0.3.1.6 | Serial up-link shall allow for 2 bytes per command | 0.3.1 |
| 0.3.1.7 | Payload shall use a DB9 connector, RS232 protocol, with pins 2, 3 and 5 | 0.3.1 |
| 0.3.1.8 | Payload shall transmit payload status to the HASP serial downlink | 0.3.1 |
| 0.3.1.9 | 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 | The optics system 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 |

# III. Design

## A. Optics

The HELIOS IV optics system is composed of two camera systems with two separate objectives. The ADCS camera system is designed to characterize the tracking system. The science camera system is designed to capture images of sunspots in the hydrogen-alpha wavelength, while still being capable of capturing the entire disk of the sun. These two camera systems will be mounted parallel to each other in the camera housing.

The optics system has the same basic design as the one flown on HELIOS III. Changes that have already been implemented consist of shortening the focal length from 255 mmm to 250 mm to increase focus and adding a solar filter to decrease the light intensity and reduce reflections. The optics team also plans to move the stack of filters forward to make better use f the UV filter.

Figure 2: ADCS Camera equipped with two neutral density filters

### *1. ADCS Camera System*

The purpose of the ADCS camera system is to qualitatively measure the performance of the sun tracking system. Equipped with a large field of view, the camera housing will only need to be pointed in the general direction of the sun in order for the ADCS camera to capture it. This camera system could give the HELIOS IV team a good visualization of how well the photodiodes are tracking the sun, as well as being used to calibrate the photodiodes.

The ADCS camera system shown in Figure 2 uses a DMK 42AUC03 camera that has a 1/3 CMOS sensor chip with a 1280 x 960 pixel resolution, and a global shutter. In front of the camera is a camera lens with an adjustable 28mm aperture and two neutral density filters. The camera lens has a 12mm focal length that gives the ADCS camera system the field of view of 22.9° x 17.2° . The suns diameter is approximately $1.39 \times 10^6$ km and the Earth is at an average distance of $1.496 \times 10^8$ km away from the sun, which results in an angular diameter of approximately 0.532° , or $1883''$. This means the resulting picture on the CMOS chip will be $64.5\,''$/px, or 47.583 km/px, based on the linear diameter of the sun being approximately 738.2 km/$''$. The resolution quality on the ADCS camera system is not of utmost importance. However, it is important to ensure that the incoming light from the sun doesn't damage the CMOS sensor chip. Therefore, there are two neutral density filters placed on the front of the camera lens that each have different optical densities. The very front neutral density filter has an optical density of 0.9 OD and the filter behind it has an optical density of 3.0 OD, which adds to 3.9 OD. This equates to only 0.0122 percent of the visible light from the sun transmitting through the neutral density filters to the sensor. The filters screwed into the front of the camera lens, with the assistance of some aluminum tape, and the camera lens is a standard C-mount thread.

### *2. Science Camera System*

The science camera system is designed with the objective of capturing images of the entire disk of the sun in the hydrogen-alpha wavelength in order to observe sunspots on the sun's surface. The suns surface contains a large proportion of hydrogen that emits hydrogen-alpha light waves when an electron falls from its third to second lowest energy level. This wavelength is extremely useful for viewing surface features, such as sunspots, and hence has been selected as the wavelength of choice for the HELIOS IV science camera system.

The science camera system is equipped with a DMK 51BU02 camera that has a 1/18 CCD sensor chip with 1600 x 1200 pixel resolution, and a global shutter. The global shutter collects the image on each pixel at the same time, which results in less blur than a rolling shutter. In front of the camera, is a C-mount tube, with a 25 mm aperture, comprised of multiple pieces screwed together. The C-mount barrels are made of black anodized aluminum, which help minimize out-gassing, and are standard pieces that don't need to be machined. About a third of the way from the end of the barrel lies the piece containing the three glass filters, including the hydrogen-alpha filter, represented by the red piece in Figure 3. The objective lens lies in the front piece, represented by the yellow piece, and the solar filter taped taut at the very front of the barrel, in front of the objective lens (Figure 3). The solar filter is a thin film that has an optical density of 5.0 OD, which decreases the intensity of the incoming light to only 1/1000 of 1 percent being transmitted. This filter acts like like a neutral density filter; however, it extends beyond the spectrum of visible light into UV and IR light. The other three glass filters sit, in the red piece in Figure 3, in the following order: one dichroic longpass filter (purple), that filters UV light, one hot mirror (green), which filters IR light, and one narrow band-pass filter (red) with a 10 nm bandwidth that passes light at 656 nm (hydrogen-alpha filter)(Figure 3). The lens in the front piece is a single objective lens, placed and held by two retaining rings, with a 250 mm focal length. The 250 mm focal length is used to obtain the desired field of view of 1.95° x 1.56° .

This field of view ensures that the entire disk of the sun, the diameter being about 0.532° , can be captured without sacrificing magnification or resolution quality. Based on the same linear diameter of the sun as above, the science camera system achieves a plate scale of 3.63 ″/px, or 2679 km/px. However due to the 25 mm aperture and 656 nm wavelength, the diffraction limit is approximately 6.606″. This means that two features must be at least 4876 km away from each other on the surface of the sun in order to distinguish the two features. The diameter of a sunspot can be anywhere from 16 km to 160,000 km, so the science camera system shall be able to see any sunspots with a diameter larger than 4876 km.

Figure 3: Science Camera System fully equipped with a solar filter, IR filter, UV filter, and H-alpha filter.

## B. Structures

The HELIOS IV payload consists of three major structures, the base housing, the intermediate structure, and the camera housing which can be seen in figures 17 on page 30, 18 on page 31, 19 on page 32. The payload has five assemblies: one for each of the three structures, the azimuth axle assembly, and the two baffled photodiode arrays.

The base housing has three major components: a base plate, shown in figure 20 on page 33, structural pillars, and a top plate, both shown in figure 19 on page 32. Pillars are used in place of a truss because they are significantly lighter and easier to machine. The intermediate structure has a circular plate connected to two arms that secure the camera housing. One arm will hold motor mounts that will support the elevation motor. The camera housing consists of a bottom plate and two side plates. The azimuth axle assembly contains four components: an axle, a gear, bearings, and a flanged hub. This flanged hub connects the axle assembly to the top plate, and the circular plate is held to the axle by a large nut. The photodiode housings are comprised of two parts, a top and a bottom, and are 3D printed.

This structure is made entirely of 6061 Aluminum alloy with the exception of the gear, which is made from steel, and the photodiode housings, which are made from acrylic plastic. Helicoils are used to prevent thread wear as well as provide an easier method for assembly. A custom base plate is used to allow for better thermal efficiency, and is explained more in depth later.

To ensure enough torque is provided to rotate the housing, a 4:1 gear ratio is used for the azimuth axis. With proper balancing a 1:1 gear ratio should suffice for elevation.

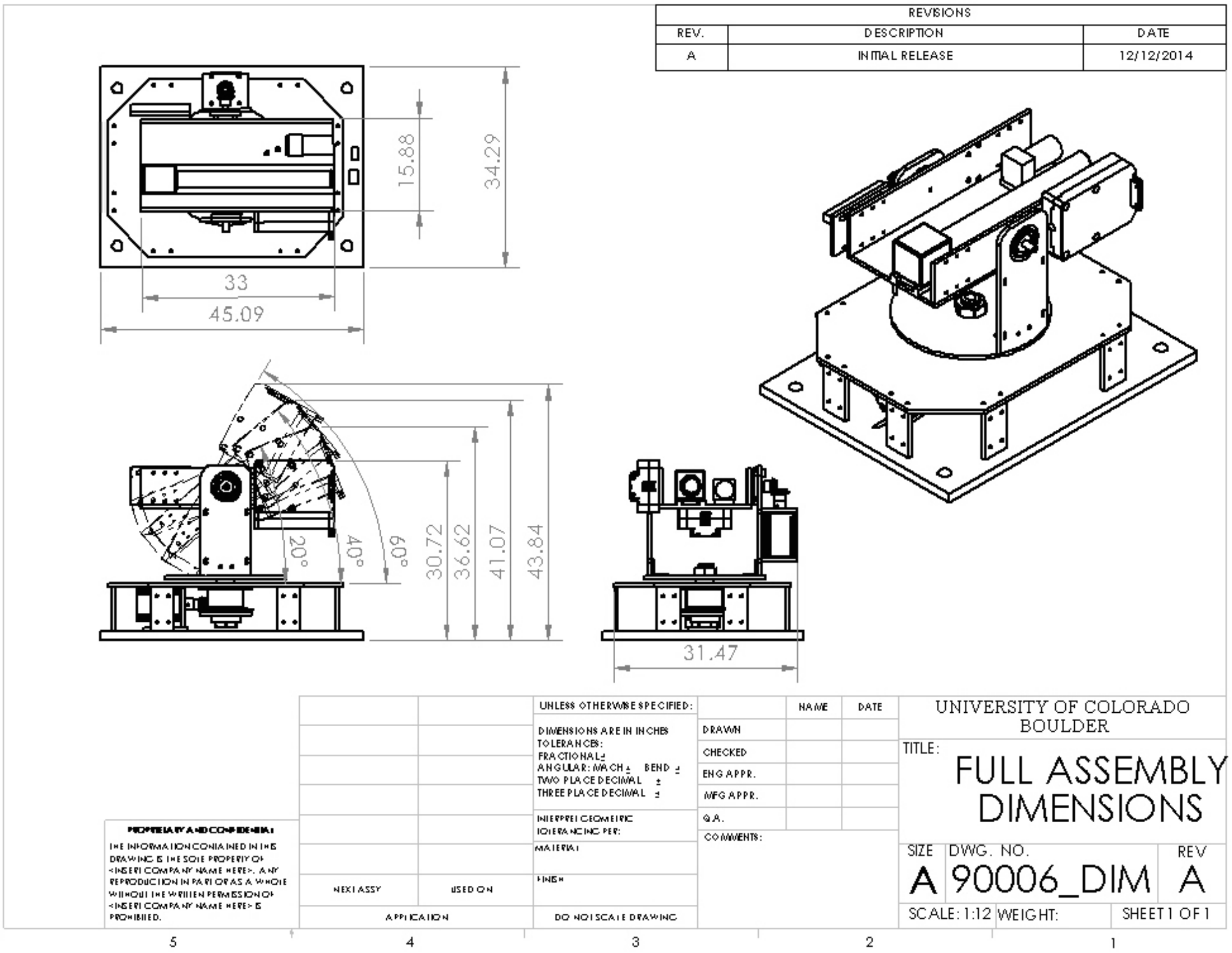
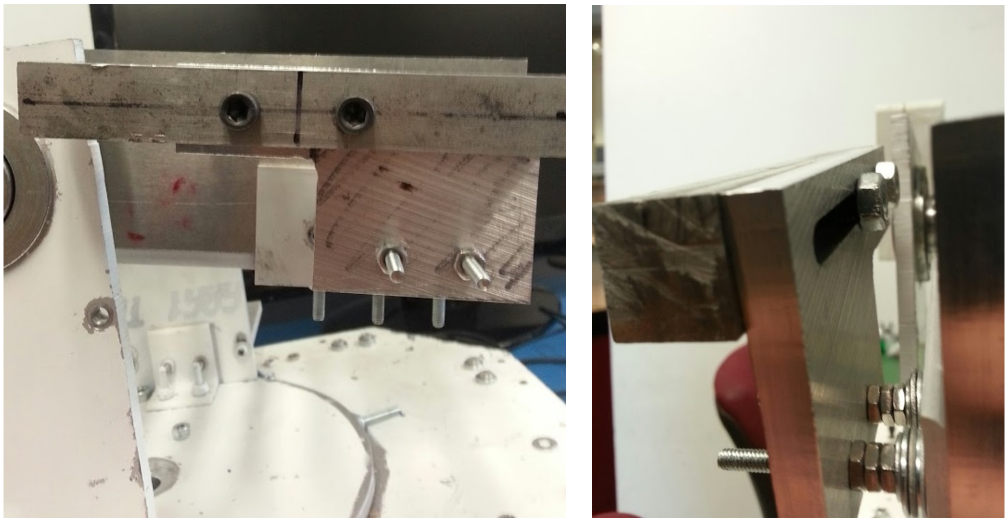


Figure 4: Full Structure Assembly

A major problem with the structure for HELIOS III was gear alignment and proper meshing. Thus, slots are cut into the base plate to provide a way to adjust the contact ratio of the gears. Slots are also cut into the arm of the intermediate structure to allow for vertical motion of the motor, which provides a way to adjust elevation gears. Another problem encountered was proper balancing of the camera housing. In order for the elevation motor to rotate the camera housing it must first be balanced. A dual axis slotted weight system is implemented to provide balance adjustment of the camera housing. This enables the elevation motor to rotate the housing with ease.

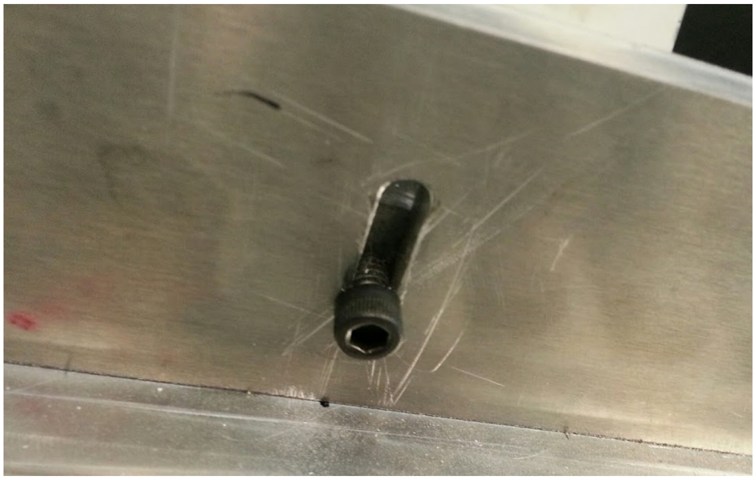
The azimuth axle has threaded ends for large nuts to screw onto and secure both the gear and the intermediate housing. A through hole is drilled in the axle for wires to run up to the camera housing, minimizing any tangle that would occur.

Since the HELIOS III flight, the structures team has made the structure easier to take apart and put together by replacing the brackets with through holes. They have balanced the structure to make it easier to turn on elevation, and have modified the intermediate structure so that the elevation gear assembly meshes better. They are currently in the process of assembling a new structure completely separate from HELIOS III, but still based on the same design.



(a) Slotted Weight for Balancing

(b) Slot used to adjust the weight



(c) Slots cut into camera sides used to adjust the height of the center of mass

Figure 5: Balancing mechanisms implemented on the camera housing

While HELIOS IV is in the process of being manufactured, HELIOS III is being used to test some solutions to problems encountered during the 2014 flight. Shown in Figure 5 on the preceding page are the current methods used to balance the structure. A weight was implemented to balance the camera housing, shown in Figure 5a on the previous page. The weight can be adjusted via a slot as shown in Figure 5b on the preceding page, giving control over one axis for balancing. Because the center of mass was below the pivot point, the center of mass would tend to return to its equilibrium point. This issue was solved by adding slots on the camera housing sides, as shown in Figure 5c on the previous page, and the housing was thus balanced.

#### a. *Structural Integration*

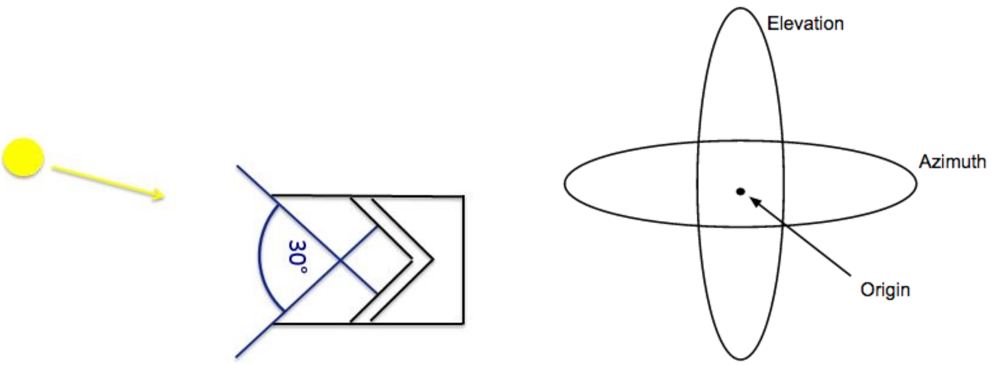
The HELIOS IV payload will be integrated with the HASP structure with four bolts. As a custom plate is used, great care must be taken when machining the base plate. The four holes will be measured against the original provided plastic plate to ensure proper hole alignment as well as DVB9 and EDAC placement.

## C. Attitude Determination and Control System

The primary task of the ADCS is to locate the sun in the sky and orient the camera housing towards the sun. Two photodiode arrays shall be attached to the camera housing. The array on the right of the camera housing will detect the light along the y-axis or the elevation, while the array on the bottom of the camera housing will detect the light along the x-axis or azimuth. Figure 8 on page 14 shows the positioning of the photodiode arrays relative to the camera housing. The Raspberry Pi B+ micro processor shall collect the photodiode readings and determine how far off from the sun the camera housing is. Then the Pi will command the stepper motors to move the camera housing. While it is doing this, the Pi will also calibrate the photodidodes by analyzing the diode readings and the images being taken of the sun with the ADCS camera.Methods of analysis are discussed later in this section. One motor will move the camera housing along the azimuth, and the second motor will move the camera housing along the elevation. The Pi will command the motors to rotate the camera housing until the photodiodes and therefore the cameras are centered on the sun. The system shall track the sun constantly throughout flight to compensate for the rotation of the platform.

ADCS is almost identical to the system used on HELIOS III. The only change that has been made so far is the implimention of a different motor driver that allows for more current. Light tracking has been accomplished with the photodiode arrays used for the HELIOS III flight and the new drivers. In addition, software for real-time photodiode calibration is currently in developement.

### 1. *Photodiode Arrays*



(a) Photodiode Housing Diagram

(b) Elevation and Azimuth

Photodiodes shall be used to measure light from the sun. The photodiodes output a current based on the amount of light measured by the sensor. As the light measured by the sensor increases, the photodiodes will output more current. If no light is detected by the photodiodes, the photodiodes will output a dark current. The dark current for the photodiodes is about 0.1 nA. The current output by the photodiode is very small, outputting a max current of about 0.04 µA. Because of this, the Pi would be unable to read changes in the raw output signal. To compensate, the ADCS will reverse bias the diodes by supplying 3.3 V backwards through them, boosting the voltage across the two ends of the diode so that the Pi can easily read the difference. With the reverse biasing, the photodiodes will output 3.3 V in complete darkness and 0 V at full light saturation.

Two photodiode arrays shall be used in the ADCS. Figure 7 displays an image of the photodiode array. One photodiode array will read light intensity on the azimuth, while the other array shall measure the light intensity on the elevation. Each photodiode array shall contain two small diode boards and each board will contain two photodiodes, one primary diode and one backup diode, for a total of eight photodiodes in the system.

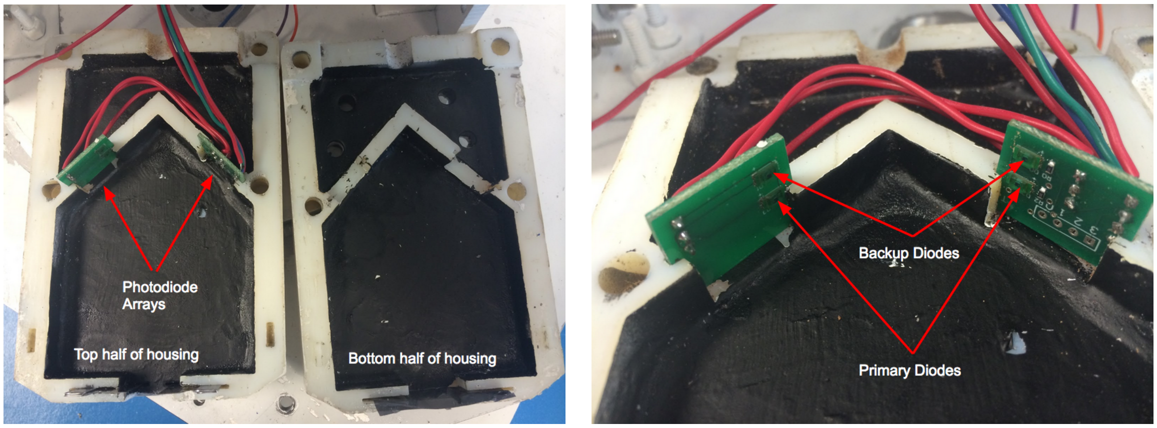


Figure 7: Internal Photodiode Arrays

The housings are 3D printed in two separate pieces and are rectangular boxes. The inside of the housings create a 90° angle at which the photodiodes will be set. The geometry of the array is designed to maximize the ability of the photodiodes to track the sun. If the sun is in the center of the array, each photodiode in the pair reads the same light intensity. If the sun is off center but still in the field of view of the photodiode array, one photodiode reads a greater light intensity. The photodiodes are very sensitive to changes in angle of incoming light. The photodiodes have a maximum sensitivity to light angle changes at 45° from the normal. Based on the geometry of the array, when the sun is in the center of the array, it will be at a 45° angle from the photodiodes. Therefore, the diodes are positioned in the array so that they will be at their max sensitivity to change when the sun is near centered on the array. The housings are also built to baffle the photodiodes so that light reflected off the balloon or the platform will not skew the photodiode readings. This also means that the field of view of the diodes is limited to approximately 30° in either direction. This is illustrated in Figure 6a on the preceding page.

When pointed directly at the sun, the photodiodes would become saturated. In order to solve this problem, light diffusers are placed in front of the photodiodes. The light diffusers are neutral density filters cut to fit in the opening of the photodiode housings. The filters are neutral density gels and block 75% of the incoming light, ensuring that the diodes do not become over saturated while still allowing for accurate readings. Furthermore, to compensate for any light reflecting off of the baffles, two razor blades are set at the opening of the diode housings. Electrical tape is placed around the junction of two halves of each housing to ensure that no extra light reaches the diodes. This is illustrated in Figure 8 on the next page.

### *2. Stepper Motors*

A stepper motor will be used to move the camera housing by rotating it in azimuth. The motor is a bipolar motor with 200 steps per revolution that takes 3.2 V at 2.8 A. A stepper motor driver will be used to control the motor, and the Raspberry Pi microprocessor will send commands to the driver. The driver will be used to power the motors and will receive 10.8V of power from the EPS board. The driver has a built in current controller that allows the driver to run with up to 2 A, though current above 1.2 A requires a heat sink in order to not overheat the driver. The driver is shown in Figure 9 on the following page. This driver allows for much more current than the driver used for HELIOS III, which limited the current at 750 mA. The

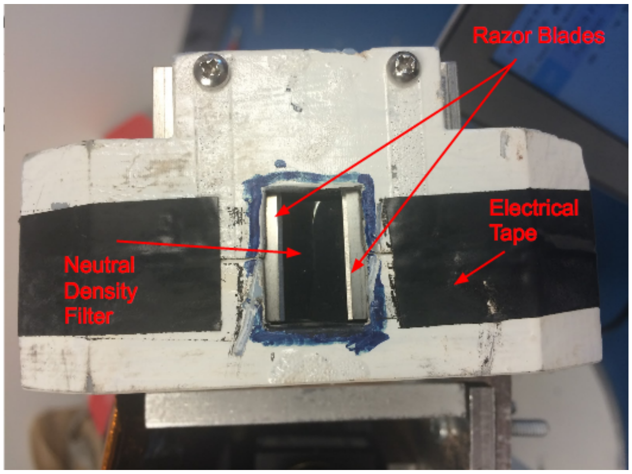


Figure 8: Photodiode Housing

higher current will help in allowing the system to turn on elevation as well as azimuth, since during the last iteration of the mission the motor did not get enough power to turn the camera housing on elevation.

The driver will allow the motor to micro-step. Eight-step micro-stepping will be used, allowing the motor to move 1600 steps per revolution. With the four to one gear ratio, the motor will be able to move 6400 steps per revolution. This will greatly increase the smoothness of the movement and allow the system to point at the sun with an accuracy of 0.05625° . Since the field of view of the science camera is only 1.5° by 2° , a high degree of accuracy is needed to ensure that the sun can be captured in the images.

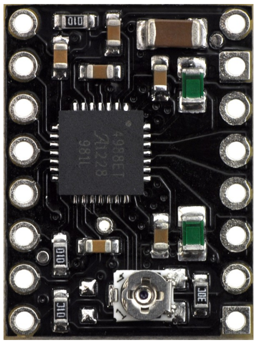


Figure 9: Stepper Motor Driver [a]

### *3. Control Algorithm*

The ADCS Control algorithm consists of a single main flight loop, with several manual and automatic commands to respond to various situations encountered during flight. The ADCS system is controlled based on three data inputs: i) numerical readings from the azimuth diodes; ii) number of steps taken by the azimuth motor; and iii) live video data from the on-platform HASP live-streaming camera. These data sets are used to perform three different functions during flight: i) sun-tracking in azimuth; ii) resetting the azimuth location to zero; and iii) nudging in azimuth to find the sun. Each of these functions will be performed based on each of the three data sets, respectively. The control algorithm is illustrated graphically in Figure 10 on page 16.

#### *a. Diode Readings and Sun-Tracking*

Throughout flight, the two diode pairs will collect data in the form of the voltage drop across the each diode. In order for the Raspberry Pi to read these voltages, the diode outputs will be run through Analog to Digital Converters (ADCs) , which will return signed 16 bit binary numbers, in the form of the difference in readings between the two diodes of a pair. The diode readings will be run through a moving average in order to smooth out the readings and minimize electrical interference and variability.

These averaged readings will be used used to track in azimuth and elevation. If the readings are greater than a set tolerance value, the microcontroller will tell the motor driver to turn the motor one microstep in the clockwise direction. If the readings are lower than the negative of the set tolerance value, the microcontroller

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[a] Taken from: `http://www.pololu.com/product/2128`

will tell the motor driver to turn the motor one microstep in the counterclockwise direction. Readings above the tolerance correspond to the diode on the left of the azimuth diode housing reading greater than the one on the right, and therefore the sun being on the right of the payload when looking from the point of view of the payload. Readings below the tolerance correspond to the opposite of readings above the tolerance.

The diodes will constantly read voltage drop, and the ADCs have a sampling rate of 6 Hz. Therefore, the motor will be able to turn one step every seventh of a second, as in the ADCS algorithm the motor is capable of turning one step for every diode reading. The tolerance value is implemented due to the natural electrical noise and variation in the diode readings. Without the tolerance, the housing would constantly move back and forth as the motor turned with changing diode readings. The tolerance allows for the housing to not move when the diodes are centered on the sun within that tolerance.

Furthermore, the photodiodes will be dynamically calibrated by the Raspberry Pi. The photodiodes will provide a rough estimate of where the sun is located relative to the payload, placing the sun within the frame of the on-board ADCS camera. The ADCS camera will then periodically take pictures of the sun, and use the Canny Line Detection and Hough Circle Transform algorithms to determine the center point of the sun. With the center point located in pixels, the distance from the center of the image to the center of the sun will be calculated by the Raspberry Pi. This distance will then be used along with the voltage difference readings from the photodiode pairs for calibration and adjustment of the system.

### *b. Motor Steps and Resetting the Location*

Throughout flight, each step that the azimuth motor takes shall be recorded in a step count. This step count shall be constantly downlinked to the ground through the HASP platform. The step count will be initialized at zero, and every time the motor takes a step in the clockwise direction, the step count is increased by 1. Likewise, every time the motor takes a step in the counterclockwise direction the step count is decreased by 1.

For movement in azimuth, a full step for the motor corresponds to turning 1.8° . The motor driver will be set to have the motor take eighth steps, corresponding to 0.225° per step. The azimuth motor system will be connected to the top housing via a gear system with a 4:1 gear ratio. This gear ratio will decrease the number of degrees taken per step by the magnitude of the ratio. Therefore, one step taken by the motor will move the camera housing by 0.05625° . This means that 360° or one revolution about the axis is equivalent to the motor taking 6400 steps in either direction.

Once the system steps 360° in either direction, it will automatically turn back 360° to reset to the orgin. This prevents the wires running from the base housing to the camera housing from getting tangled or pulling out of the components.

For movement in elevation, the motor driver will be set to have the motor take eighth steps, as it does in azimuth. The motor will be connected to the system via a 1:1 gear ratio, so the number of degrees taken per step will be 0.225° . This means that 360° or one revelation is equivalent to the motor taking 1600 steps in either direction. Once the system turns 70° upward, or approximately 310 steps, the algorithm will prevent it from moving upward anymore so the the camera housing will not try to move higher than it is structurally able. The same will occur if the camera housing tries to turn below 0° .

### *c. Live Video Data and Nudge Commands*

During flight, the HASP Platform will broadcast a live feed from a video camera stationed on the ladder of the balloon above the platform. HELIOS IV will be able to be be clearly seen from this video feed. The data received from this video feed is qualitative. Nudge commands will be implemented that allows the HELIOS IV team to manually turn the platform at 10° or 90° intervals if they visually observe that the payload is pointing away from the sun.

### *4. Test Procedure*

The ADCS 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. 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.

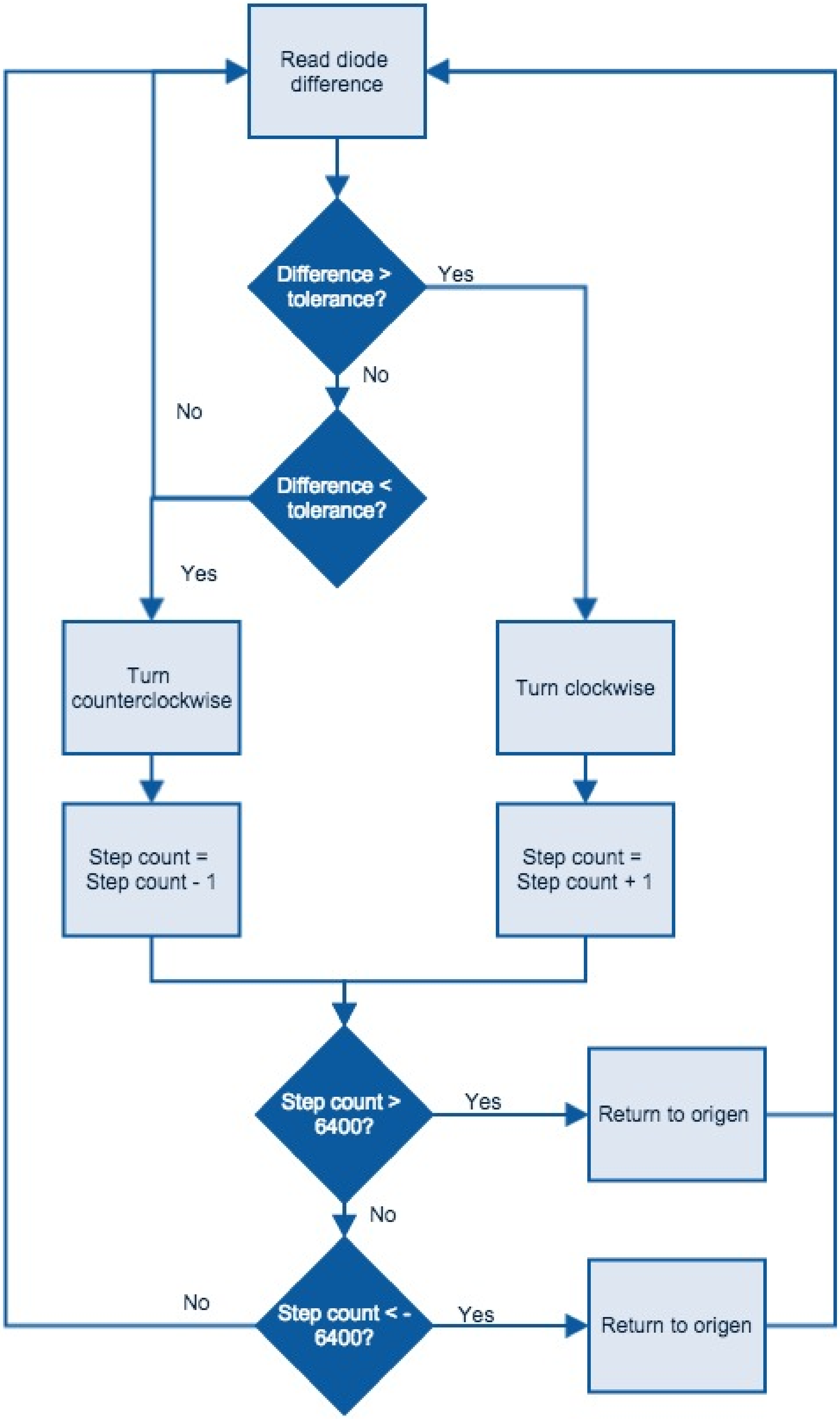


Figure 10: ADCS Algorithm

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 systems ability to maintain the sun in its field of view, the system will be rotated at a rate comparable to the expected rate of rotation of the HASP platform. To test the systems ability to regain the sun, the structure will be repositioned so the system is facing away from the sun. Nudge commands will be used until the payload locks onto the sun again. All of these tests mimic expected light or movement conditions during flight. 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.

### D. Electrical and Power System

HELIOS IV shall receive 30 Volts DC from the HASP platform. Two DC-DC buck converters shall be used to immediately step down the voltage from 30 Volts to 12 and 5 Volts. A simple trimming resistor will be used to bring the 12 Volt line down to provide the correct 10.8 Volts necessary for the elevation and azimuth motors. Each component shall have its own power protection system built in to eliminate the need for exterior monitoring.

| Component | Voltage (V) | Current (A) | Power Draw (W) |
|---|---|---|---|
| Raspberry Pi | 5 | 1.1 | 5.5 |
| Gertduino | 5 | 0.5 | 2.5 |
| Motor Driver 1 | 10.8 | 0.75 | 8.1 |
| Motor Driver 2 | 10.8 | 0.75 | 8.1 |
| USB Hub | 5 | 2 | 10 |
| | | Total Power Draw | 34.2 |

Table 2: EPS Power Budget

A power budget is laid out in Table 2. This includes all major components of the electrical system at their maximum voltage and current draw. Even in these conditions, the maximum power used is 58.7W. Because the voltage from the HASP platform is 30 Volts, the maximum current draw from the platform is 1.96A. This is well under the maximum current limit of 2.5A and will not be a risk.

The EPS team for HELIOS IV began work by redesigning the PCB used for the HELIOS III flight. Since most of components were already working together and implemented in the schematic, relatively minor changes were need to fix problems that were encountered by the HELIOS III team. Because of this base, a PCB has already been manufactured from the schematic shown in Fig. 25 on page 38 and is currently in the testing phase. The PCB is smaller and more space efficient than the previous iteration while still providing the necessary capabilities. An image of the power board in its current state is shown in Figure 12 on page 19.

### E. Command and Data Handling

The CDH system aboard HELIOS IV will be responsible for communications with the HASP platform and collecting and managing data from the Optics, EPS, and ADCS subsystems. As such, the design of the CDH system shall utilize a Raspberry Pi B+ microcontroller, Gertduino, and flight code written in C++ and Python. The Gertduino is a board similar to an Arduino Uno with an added microcontroller, RTC, and RS232 level controller, specifically designed to be used with a Raspberry Pi. Both pieces of hardware are depicted in figure 14 on page 20 and an FBD of the design can be seen in figure 13 on page 19.

#### *1. Raspberry Pi*

The Raspberry Pi shall be the main component in the CDH design, controlling communications with the platform and Gertduino, capturing images, and supporting the ADCS subsystem. The Raspberry Pi shall be connected to the photodiode arrays and motor drivers and control sun tracking. It shall also be connected to the platform using a RS232 to USB converter for serial communications and both cameras using USB 2.0.

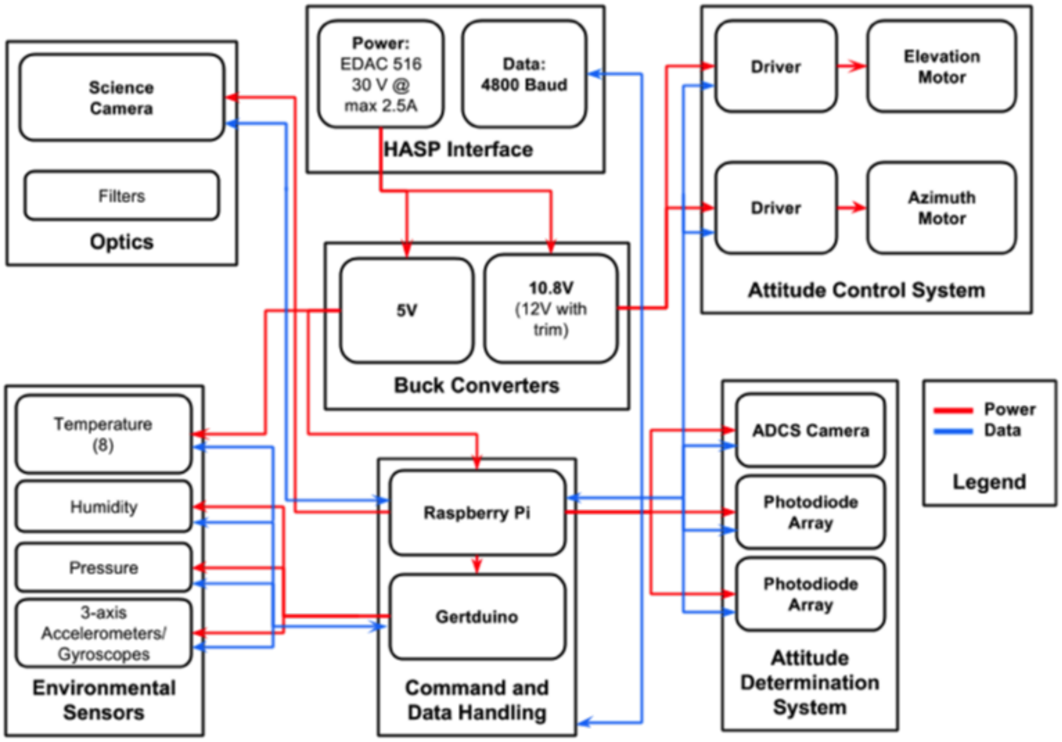


Figure 11: EPS FBD

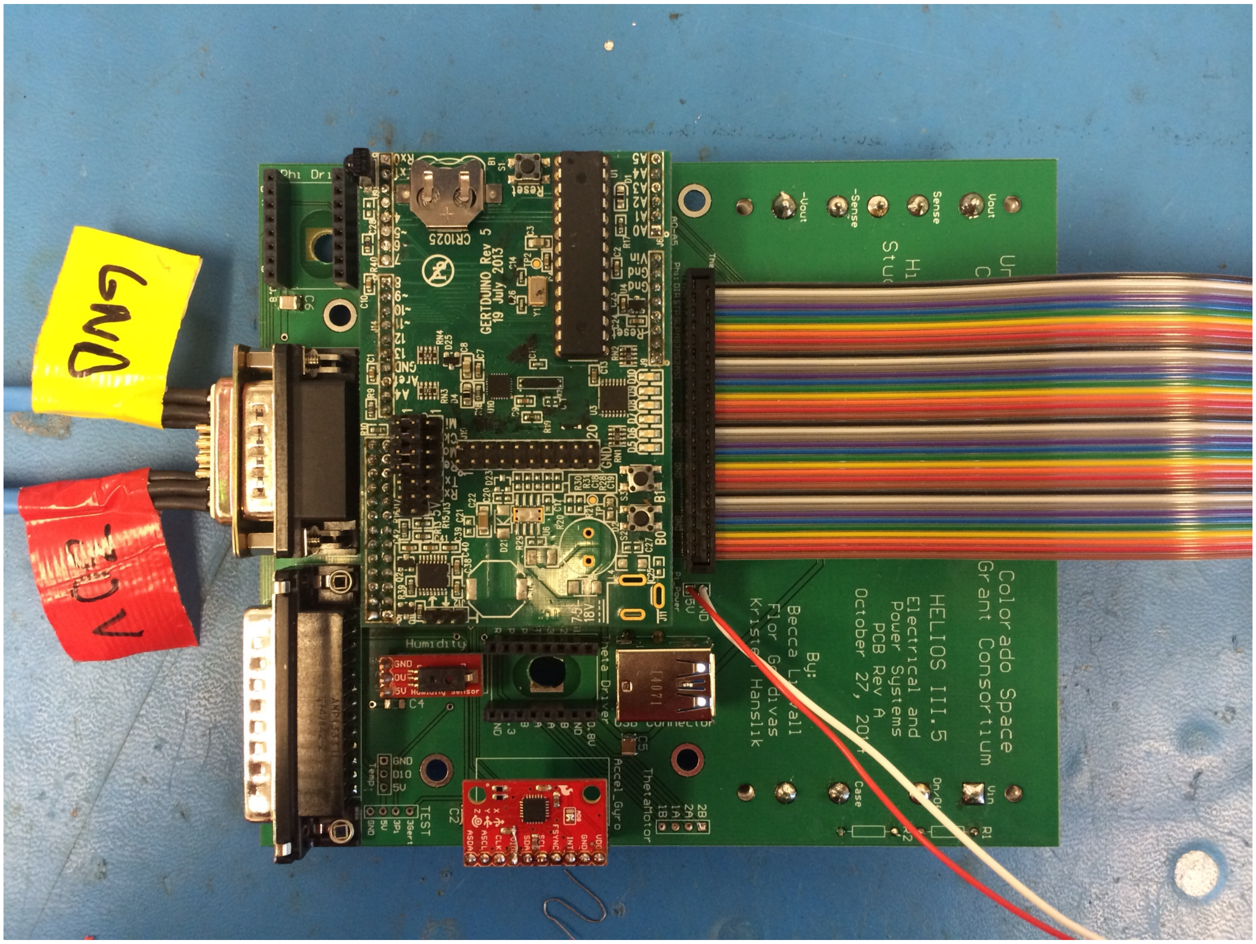


Figure 12: EPS Power Board

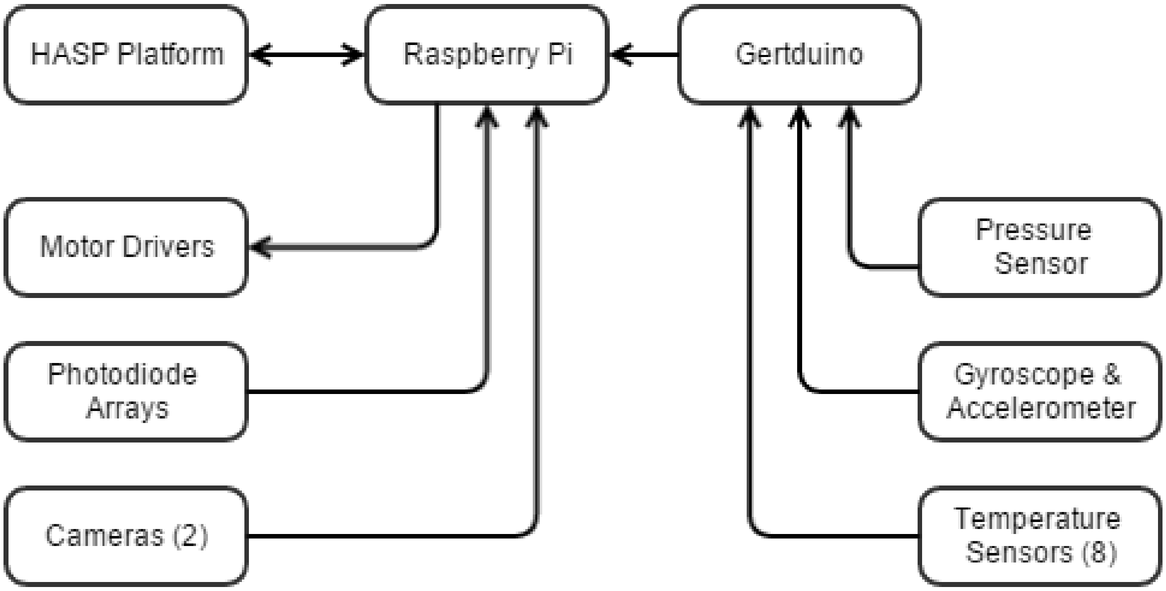
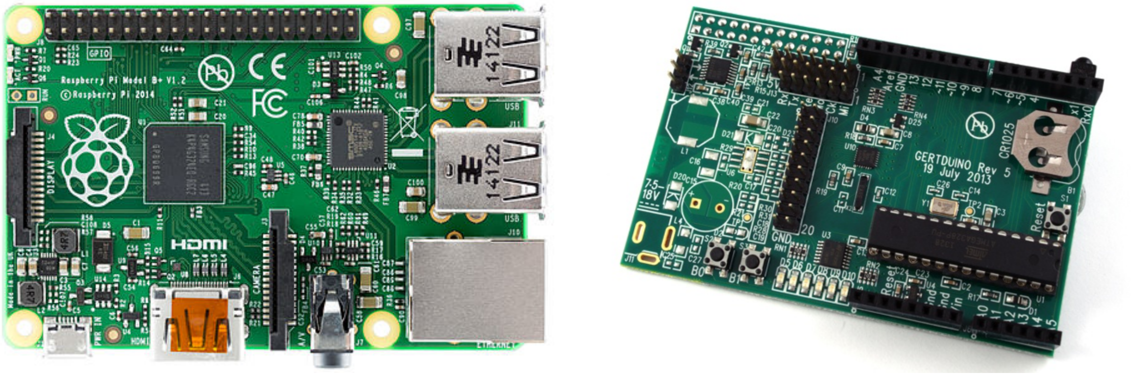


Figure 13: CDH FBD



(a) Raspberry Pi (b) Gerduino

Figure 14: CDH Flight Hardware

In order to handle this variety of goals, the Raspberry Pi shall run flight software that shall be separated into 5 distinct threads. This allows the threads to run concurrently on the processor without allowing one thread to monopolize the processor. The threads shall utilize locks and semaphores to prevent attempted concurrent use of the communication buses, files, or other single-actor resources, and pass data between themselves with queues. The threads are documented below, with the exception of the ADCS thread which is covered in figure 10 on page 16.

### a. *Monitoring Commands from Ground - `uplk`*

The `uplk` thread is responsible for awaiting two-byte serial commands uplinked by the ground station. It idled until it detected data in the serial buffer, then passed the relevant information to the threads affected. If any issues were detected with the uplinked command, it would downlink an error to ground. Table 3 on the following page documents the commands used by the HELIOS IV team. Upon the execution of a command, the executing thread would downlink an acknowledgment. The thread would then idle until more data was uplinked to the payload. The HELIOS IV team does not expect to be uplinking more than one command per hour during flight, and will not utilize discrete commands or the GPS and time data.

| Payload Command | Two Byte Hex Command | Description |
|---|---|---|
| Reinitialize Pi Program | 0x0B 00 | Causes the flight code to reset to known state |
| Pan mode on | 0x0C FA | Toggles panning mode for total diode failure |
| Pan mode off | 0x0C FB | |
| Toggle diode pair - phi | 0x0C 1A | Toggle between main and backup diodes |
| Toggle diode pair - theta | 0x0C 0A | |
| Clean Shutdown | 0xFF FF | Allows clean shutdown of threads |
| Ping | 0xAA AA | Ping the payload to test communications |
| Nudges | 0x0C F0 | -10 Nudge |
| | 0x0C F1 | 10 Nudge |
| | 0x0C F2 | -90 Nudge |
| | 0x0C F3 | 90 Nudge |
| Autopan | 0x0C FC | 10s Panning mode |

Table 3: Command Table

### *b. Downlinking Data to Ground -* `dwnl`

This thread will process and downlink data from the other threads to be sent to ground. It will then idle until a thread passes it a data package containing the identifier of the author thread, the record type, and data. The downlink thread will then format the information into the downlink format, documented in Table 4 on the next page, along with the types of downlink packages. The goal of the downlink format is to easily identify any data loss or corruption, and allow for easy sorting. The payload will downlink this packetized data at about 350 bit/s, and no analog downlink channels will be used.

| Bytes | Content | Example |
|---|---|---|
| 0-4 | Start | STX |
| 5-7 | Payload Identifier | CU |
| 8-10 | Thread Identifier* | PI |
| 11-13 | Record Type* | AP |
| 14-18 | Timestamp | 1400019944 |
| 19-22 | Length of data | 37 |
| 23-26 | Adler32 Checksum | -71889546 |
| 27 | New line | STX |
| 28-(N-4) | Data* | The red fox jumped over the brown log. |
| (N-3)-N | End Transmission | XTX |

| Sender | ID | Record | ID | Content | Typical Data |
|---|---|---|---|---|---|
| Uplink | UP | Bootup | BU | | 0xBB |
| | | Ack | AC | Responding to ping | |
| | | Error | ER | Invalid target | <2 bytes> |
| Downlink | DW | Bootup | BU | | 0xBB |
| Gertduino | GE | Bootup | BU | | 0xBB |
| | | Downlink | DW | Data | Data Package |
| ADCS | AD | Bootup | BU | | 0xBB |
| | | Ack | AC | Command executed | <1 byte> |
| | | Error | ER | Command with error | <1 byte> |

Table 4: Data downlink format

### *c. Communicating with the Gertduino -* `gert`

The `gert` thread will be responsible for gathering information from the Gertduino and downlinking it to ground and is intended to forward commands to the Gertduino. There are no actual commands assigned to the Gertduino in the current design, so it currently forwards environmental data from the Gertduino to the downlink thread.

### *2. Gertduino*

The Gertduino is responsible for collecting environmental data and passing it on to the Raspberry Pi. It is connected to a pressure sensor, accelerometer, gyroscope, and eight temperature sensors. It shall collect data from these sensors every 5 seconds and forward the information to the Raspberry Pi via serial connection. It also will house the RTC which the Raspberry Pi will use to set its internal clock when it is powered on.

This allows for consistent time keeping between the various boot-ups of the Raspberry Pi, allowing for easy determination of what data is from flight and which is not.

### F. Thermal

To ensure that no components overheat and cause payload failure, a thermal system shall be implemented for the payload. In order to reduce the optics system's exposure to the sun, the camera housing shall be covered in multi-layer insulation (MLI). To further insulate components from external sources of heat, MLI will wrap around the outer perimeter of the bottom housing. All remaining exposed aluminum on the payload will be painted with white appliance epoxy to encourage high emissivity.

In order to heat sink components, an alternative to the standard base plate shall be used if approved by the HASP program. A half inch 6061 Aluminum baseplate shall be used to interface with the platform as well as provide a sink for heat from components. In past correspondence with the HASP program about this method of sinking, it was found that this method would not contribute significant amount of additional heat to the platform as the only metal in contact with both the payload and the platform would be the bolts that secure the payload to the platform.

The level of current drawn by the motor drivers for both motors as well as the two buck converters puts these components at greatest risk for surpassing their maximum optimal operational temperature. As damage to these components must be avoided, they shall be sinked to the aluminum baseplate. A thermal gap filler shall be used to interface between each of the buck converters and the baseplate. A copper braid shall be attached to each of the motor drivers by a non electrically conductive but thermally conductive substance and will be used to interface between the motor drivers and the baseplate.

The thermal system is almost identical to the one used on HELIOS III. The only improvements are additional temperature sensors to the baseplate to characterize its ability to act as a heat and additional external temperature sensors. Furthermore, the motor drivers shall be connected with a copper braid to the baseplate to heat sink them.

## IV. Management

HELIOS IV consists of 11 members. Each member shall work in a subsystem based on interest and/or experience with the subsystem, and each subsystem will have one team lead. HELIOS IV shall work with faculty advisors and other members of the Colorado Space Grant Consortium to ensure the successful design and construction of the payload. The members of HELIOS IV and leads are subject to change. However, the team currently contains six members from HELIOS III. The current members affiliation is based on proposal writing team, while the final team selection will occur if HELIOS IV is awarded a seat. Approximately five team members will attend integration in Palestine. At the moment, the team does not plan on attending flight due to funding, though it plans on conducting operations from COSGC in Boulder.

### 1. *Team Organization*

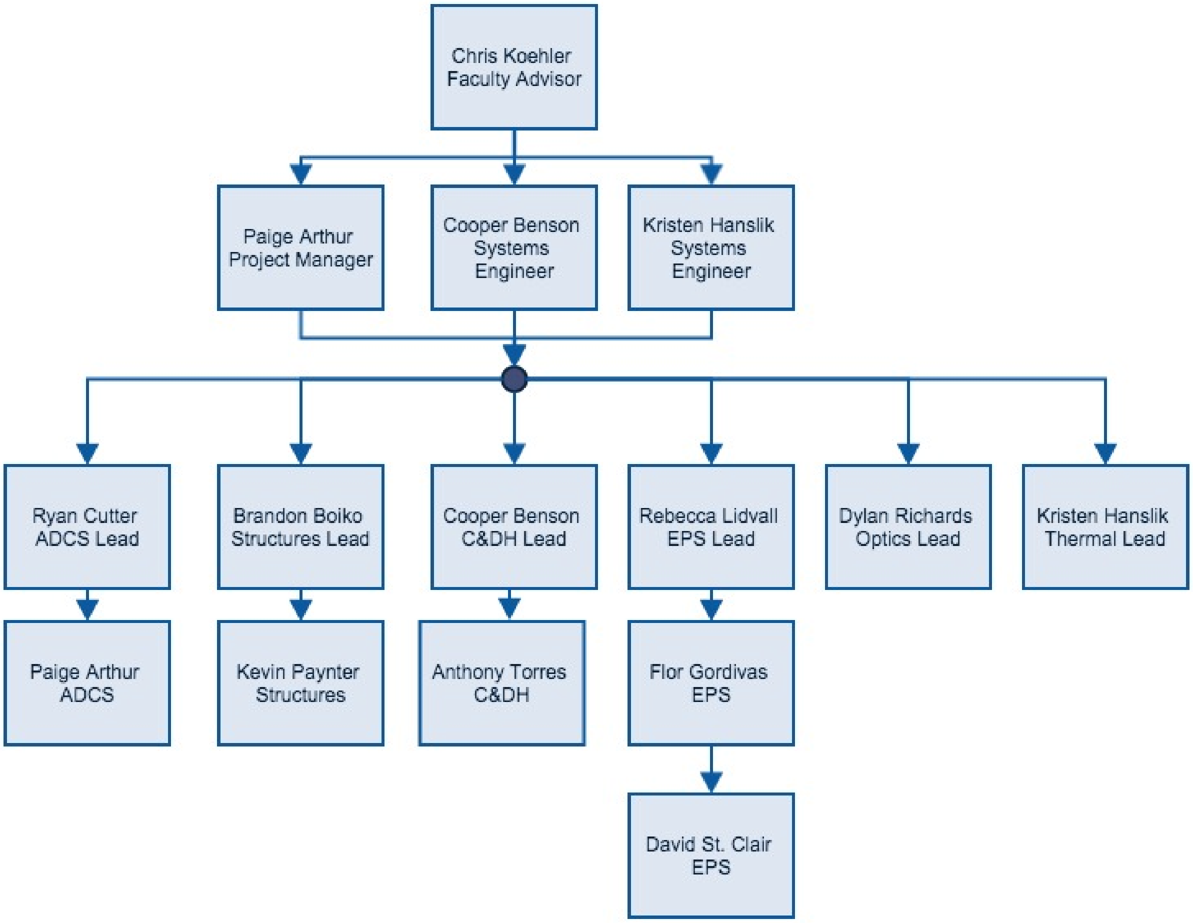


Figure 15: Team Organizational Chart

| 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 |
| Lee Sutherland | Professional Advisor | lee.a.sutherland@gmail.com | N/A |
| Paige Arthur | Project Manager | paar5780@colorado.edu | 303-957-7360 |
| Cooper Benson | Systems Engineer and CDH Lead | cobe7707@colorado.edu | 719-649-9832 |
| Kristen Hanslik | Systems Engineer and Thermal Lead | krha0428@colorado.edu | 281-615-6788 |
| Ryan Cutter | ADCS Lead | rycu2011@colorado.edu | 303-731-7220 |
| Brandon Boiko | Structures Lead | brandon.boiko@colorado.edu | 303-506-7935 |
| Dylan Richards | Optics Lead | dylan.richards@colorado.edu | 303-495-8173 |
| Rebecca Lidvall | EPS Lead | rebecca.lidvall@colorado.edu | 303-416-0366 |

### *2. Schedule*

| Milestone | NOV | DEC | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Proposal Team Formed | X | | | | | | | | | | | | | | |
| Submit Proposal | | X | | | | | | | | | | | | | |
| Payloads Selected | | | X | | | | | | | | | | | | |
| Submit Selection Response | | | X | | | | | | | | | | | | Address comments in proposal |
| New Structure Complete | | | X | | | | | | | | | | | | |
| Finalize EPS Board | | | X | | | | | | | | | | | | Tested with every system |
| Finalize Image Analysis Software | | | | X | | | | | | | | | | | |
| Finalize Optics System | | | | | X | | | | | | | | | | Cameras working simultaneously |
| Finalize ADCS System | | | | | X | | | | | | | | | | |
| Test ADCS with Image Analysis | | | | | X | | | | | | | | | | |
| Finalize Thermal | | | | | X | | | | | | | | | | |
| Full Systems Test | | | | | | X | | | | | | | | | All systems tested together |
| Final PSIP Due | | | | | | | | X | | | | | | | |
| FLOP Due | | | | | | | | | X | | | | | | |
| T-Vac Testing at CSBF | | | | | | | | | | X | | | | | |
| Integration at CSBF | | | | | | | | | | X | | | | | |
| HASP Flight Preparation | | | | | | | | | | X | | | | | |
| Target Flight Ready | | | | | | | | | | X | | | | | |
| Target Launch Date | | | | | | | | | | | X | | | | |
| Flight Operations | | | | | | | | | | | X | | | | |
| Recovery | | | | | | | | | | | X | | | | |
| Finalize Data Analysis | | | | | | | | | | | | X | | | |
| Final Science Report | | | | | | | | | | | | | | X | |

## V. Weight Budget

| Component | Weight(kg) | Quantity | Total Weight(kg) |
|---|---|---|---|
| Motor | 1.050 | 2 | 2.100 |
| Drivers | 0.003 | 2 | 0.006 |
| Diodes | 0.003 | 4 | 0.012 |
| Wires* | 0.090 | 1 | 0.090 |
| Power Board with Gertduino | 0.468 | 1 | 0.468 |
| Science Camera | 0.217 | 1 | 0.217 |
| Science Barrel | 0.171 | 1 | 0.171 |
| ADCS Camera | 0.138 | 1 | 0.138 |
| Raspberry Pi | 0.043 | 1 | 0.043 |
| Base Plate | 5.942 | 1 | 5.942 |
| Base Pillars | 0.047 | 8 | 0.376 |
| Base Top Plate | 1.802 | 1 | 1.802 |
| Circular Plate | 0.444 | 1 | 0.444 |
| Support Arms | 0.240 | 2 | 0.480 |
| Brackets | 0.018 | 2 | 0.036 |
| Camera Base Plate | 0.859 | 1 | 0.859 |
| Camera Side Plates | 0.352 | 2 | 0.704 |
| Elevation Motor Mounts | 0.082 | 2 | 0.164 |
| Azimuth Motor Mount Base | 0.064 | 1 | 0.064 |
| Azimuth Motor Mount Top | 0.063 | 1 | 0.063 |
| Azimuth Gear | 0.522 | 1 | 0.522 |
| Azimuth Pinion | 0.039 | 1 | 0.039 |
| Elevation Miter Gears | 0.039 | 2 | 0.078 |
| Azimuth Axle | 0.107 | 1 | 0.107 |
| Flanged Hub | 0.134 | 1 | 0.134 |

| Component | Weight(kg) | Quantity | Total Weight(kg) |
|---|---|---|---|
| Ball Bearings | 0.019 | 4 | 0.076 |
| Photo Diode Housings | 0.281 | 2 | 0.562 |
| Counter Weight Slot | 0.068 | 1 | 0.068 |
| Counter Weight | 0.122 | 1 | 0.122 |
| Large Nuts | 0.085 | 2 | 0.170 |
| Multilayer Insulation* | 0.100 | 1 | 0.100 |
| Thermal Gap Filler* | 0.050 | 2 | 0.100 |
| Copper Braid* | 0.150 | 2 | 0.300 |
| Total | | | $16.557 \pm 0.250$ |

This weight budget was created by measuring or calculating the mass of components. Calculations were done using SolidWorks and the structural designs. Items marked with an asterisk were estimated and a margin of error is included in the uncertainty.

## VI. Integration

Upon integration of HELIOS IV with the HASP platform, all System Leads, the Systems Engineers, 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 IV payload. The Systems Engineer shall test all communication processes and equipment throughout integration to assure proper function. The following is a detailed integration plan HELIOS IV will follow at CBF in Palestine, TX.

1. Arrive with payload assembled
2. Ensure that all components are intact after transportation
3. Test payload to ensure proper functionality
    (a) Perform test outside to allow for sun-tracking
    (b) Power on and let run through start-up
    (c) Determine that sun-tracking capability is functional
    (d) Check SD card to ensure the system captured images from both cameras
    (e) Recalibrate and realign system if determined necessary
    (f) Repeat steps 1-3 if necessary
    (g) Use switch to ensure ADCS does not attempt to rotate the motors during T-VAC
    (h) Repeat steps 1-3
4. Deliver payload to be weighed and have serial communication capability confirmed
5. Deliver payload to be integrated on the platform
6. Checks to confirm successful integration:
    (a) During T-Vac
        i. Look in data packets for startup notification downlink
        ii. Data is downlinked from the payload and the following can be seen in the data logs:
            A. Photodiode readings (from both azimuth and elevation arrays)
            B. Accelerometer readings
            C. Gyroscope readings
            D. Temperature readings

        E. Pressure sensor readings
        F. Humidity sensor readings
    iii. Graphs of downlinked sensor data made during T-Vac show nominal results. Graphs of downlinked environmental data taken by the payload approximately correspond with graphs of environmental data taken by the HASP platform.
    iv. Uplink to payload the command 0xAAAA which will ping the Gertduino as documented in the uplink commands table. Look for response from payload in the downlinked payload data.
    v. Monitor temperature of components as they should not fall outside of nominal ranges.
(b) After T-Vac
    i. Re-enable ADCS control of motors

The team would prefer that HELIOS IV be integrated in the same location as HELIOS III was, that is, directly in front of the CosmosCam. This would be beneficial because the team will be sending commands to nudge the system if it is observed that the system is not tracking the sun. This relies on visual observation of the payload, which is easier if the payload is directly in front of the camera. However, if this is impossible, HELIOS IV should be visible from any of the large payload slots assuming that no parts of other large payloads obstructs the view. The orientation of the payload is inconsequential since it will move to orient itself throughout flight.

## VII. 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 CDH lead shall be responsible for controlling all discrete commands to the HELIOS IV payload on the HASP Platform.

| Time | Task | Instructions | Indication of task completion |
|---|---|---|---|
| T = -5 days | Power Board Test | Provide 27 V, 30 V, and 33V to the power board from power supply. Measure lines to components. | Lines to components are in an acceptable range. |
| T = -5 days | Ensure gears are correctly aligned | Rotate housing 360 ° on azimuth and then approximately 50 ° on elevation. | Structure rotates without excessive resistance |
| T = -5 days | Camera housing properly balanced | Ensure that counterweight is in correct position to aid tracking system. | Housing will rest at correct angle |
| T = -3 days | Uplink, Telemetry, and Sensor check | Power on payload. Run though uplink commands. | Both telemetry (includes nominal sensor data) and acknowledgment received by mock ground. |
| T = -3 days | Photodiode housings correctly set up | Ensure housings are equipped with a set of diodes, a set of aperture devices, and proper undamaged neutral density filters. Ensure that screws are tightly securing the diode housings to the payload and that the housings are correctly aligned with the front face of the camera housing. | Visual confirmation that all components are in place and that the photodiode arrays are aligned. |

| | | | |
|---|---|---|---|
| T = -5 hours | Ensure that proper connections are made between components. | Check that both cameras are securely connected to power supply. Check that micro SD card is securely inserted into slot. Ensure motors and drivers are correctly connected to the mircoprocessor. | Visual and tactile confirmation of secure connections. |
| T = -5 hours | Thermal Check | Ensure that components needing to be attached to the baseplate by means of thermal gap filler are still securely attached. | Visual confirmation of full contact between component and thermal gap filler and between thermal gap filler and baseplate. |
| T = -5 hours | Payload Tracking Capability | Power on payload. Allow payload to run for a 5 minute period of time. Then check both ADCS and Science images on micro SD card. | Payload orients the camera housing towards the sun. Image of sun is in at least 5 ADCS pictures. |
| T = -1 hours | Remove lens caps | Remove the lens caps from the ADCS camera and the science camera. | Visually observe that neither lens cap is on the cameras. |
| T = 0 | Launch | Payload Powered On | Ensure data downlink is active |
| T = 1 hour | Verify Commanding | Send Ping (0xAAAA) | Ensure acknowledgment is in downlinked data |
| T = 2 hours | Begin Observation | Verify tracking and data downlink is behaving correctly. If not, send commands or power toggle the payload to compensate | |
| T ≈ 17 hours | Power Down Payload | Send shutdown command before termination | Ensure acknowledgments are in downlinked data |

# VIII. Special Requests

## A. Height and Width Extension

The current design of HELIOS IV has a static and dynamic envelope that breaks the allowable dimensions permitted for a large payload. This is due to the required size of the optics system and ADCS hardware. The static envelope is 38x31 cm and 31 cm tall, and the dynamic envelope further breaches the allowable dimensions while moving in the 360° azimuth range and 60° elevation range, being a maximum of 38x41 cm, with a height of 43.84 cm. These envelopes are similar to those of HELIOS III, excepting a 1 cm increase in the height and width of the static envelope.

Figures 21 on page 34, 22 on page 35, 23 on page 36, and 24 on page 37 depict the static position and dynamic positions that result in the largest breaches, along with the allowable envelope in green. As can be seen, the breach of the static envelope is limited to 0.43 cm of the elevation motor that extends out to the side and a portion of the photodiode array that is above the keep out area for the bolts. The dynamic breaches are also fairly limited, as only a small part of the camera housing extends out of the allowable dimensions.

As of this time, the HELIOS IV team knows of no way by which to further reduce the height or width of the system and still comply with the mission requirements as presented in this proposal or complicate the design of the system extremely, with one exception.

A maximum angle of 60° was selected as the maximum elevation as it is the highest angle that prevents the balloon from interfering substantially with sun tracking. There is potential for restricting the vertical rotation below 60° to further reduce the maximum height of the payload; however, that would significantly impact the effective tracking time available during float for very small decreases in height. Table 7 on the following page gives the tracking times at a variety of angles and the maximum height of the payload at these angles. Table 8 on the next page shows that small increases in maximum angle allows for much longer windows for tracking with very small height increases. For example, changing the maximum angle from 50°

to 60° only increases the height by 1.02 cm and increases the tracking time by over 2.5 hours.

Greater amounts of tracking time would allow for more data, more science imagery, and a more effective use of the platform. In addition our tracking system develops a dynamic model that will improve itself over time. Therefore more tracking time would allow for a more accurate tracking system.

The current design requires a 1 cm width and height extension for the camera housing at rest, and a 10 cm width and 14 cm height extension when in motion, unless a restriction of the maximum vertical tracking angle is recommended.

| Angle (°) | Max Height (cm) | Tracking Time (min.) | |
|---|---|---|---|
| | | 8hr | 15hr |
| 60 | 43.84 | 401 | 594 |
| 50 | 42.82 | 238 | 431 |
| 40 | 41 | 124 | 317 |
| 30 | 39 | 65 | 214 |
| 20 | 36.57 | 16 | 115 |

Table 7: Maximum heights and tracking times for a variety of maximum angles

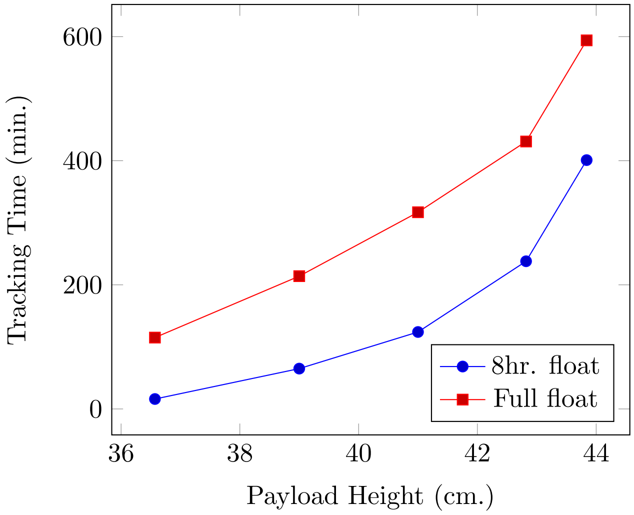


Figure 16: Plot of Maximum Height vs. Maximum Tracking Time

| Angle Range (°) | Δ Height (cm) | Δ Time (min.) | |
|---|---|---|---|
| | | 8hr | 15hr |
| 60-50 | 1.02 | 163 | 163 |
| 50-40 | 1.82 | 114 | 114 |
| 40-30 | 2 | 59 | 103 |
| 30-20 | 2.43 | 49 | 99 |

Table 8: Differences in maximum tracking time and height for 10° differences in maximum angle

### B. Custom Baseplate

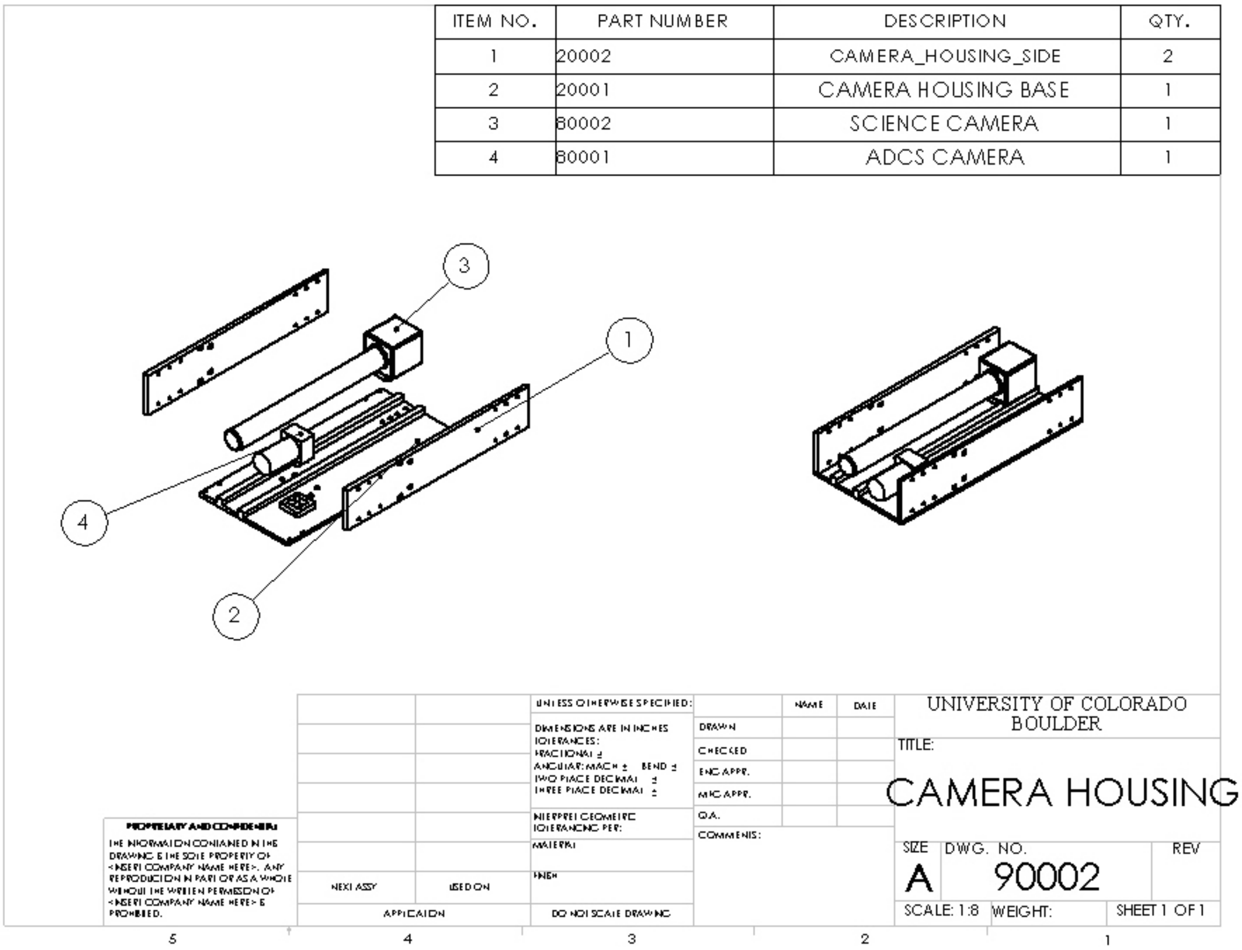
To further ensure the success of the HELIOS IV mission it is critical that components do not overheat. It has been found that two components, the two motor drivers, may be especially prone to overheating due to their high current draw and the conditions under which they shall need to perform. Two additional components that may also be at risk for overheating are the two buck converters. HELIOS II encountered this issue with one of the payloads buck converters overheating during flight. While the buck converters to be used for the HELIOS IV payload are not the same as the one used for HELIOS II, this is still an issue to be avoided. To transfer heat away from these components, a sink is needed. The use of an alternate to the standard supplied baseplate is requested. If approved, a half inch baseplate made of aluminum 6061 shall be used as a sink for components at risk for overheating.

To ensure successful integration of the baseplate and therefore the payload with the HASP platform, the baseplate created shall be checked against the standard baseplate provided in previous years to verify compatibility. Measurements for bolt, serial connector, and EDAC holes shall be taken directly from a baseplate provided to a past iteration of HELIOS and once cut the holes shall be verified directly against that provided baseplate. As the proposed baseplate shall be thicker than the standard baseplate, holes shall be inset into the baseplate to allow for the same length bolts to be used to attach the HELIOS IV baseplate as would be used to attach any other on the platform.

## IX. Conclusion

The goal of the HELIOS IV mission is to prove the viability of solar observation on board a high altitude balloon platform. HELIOS IV shall show that it is possible to adequately track the sun with a high degree of accuracy. HELIOS IV 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 IV shall compare the images taken by HELIOS IV 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 IV 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.

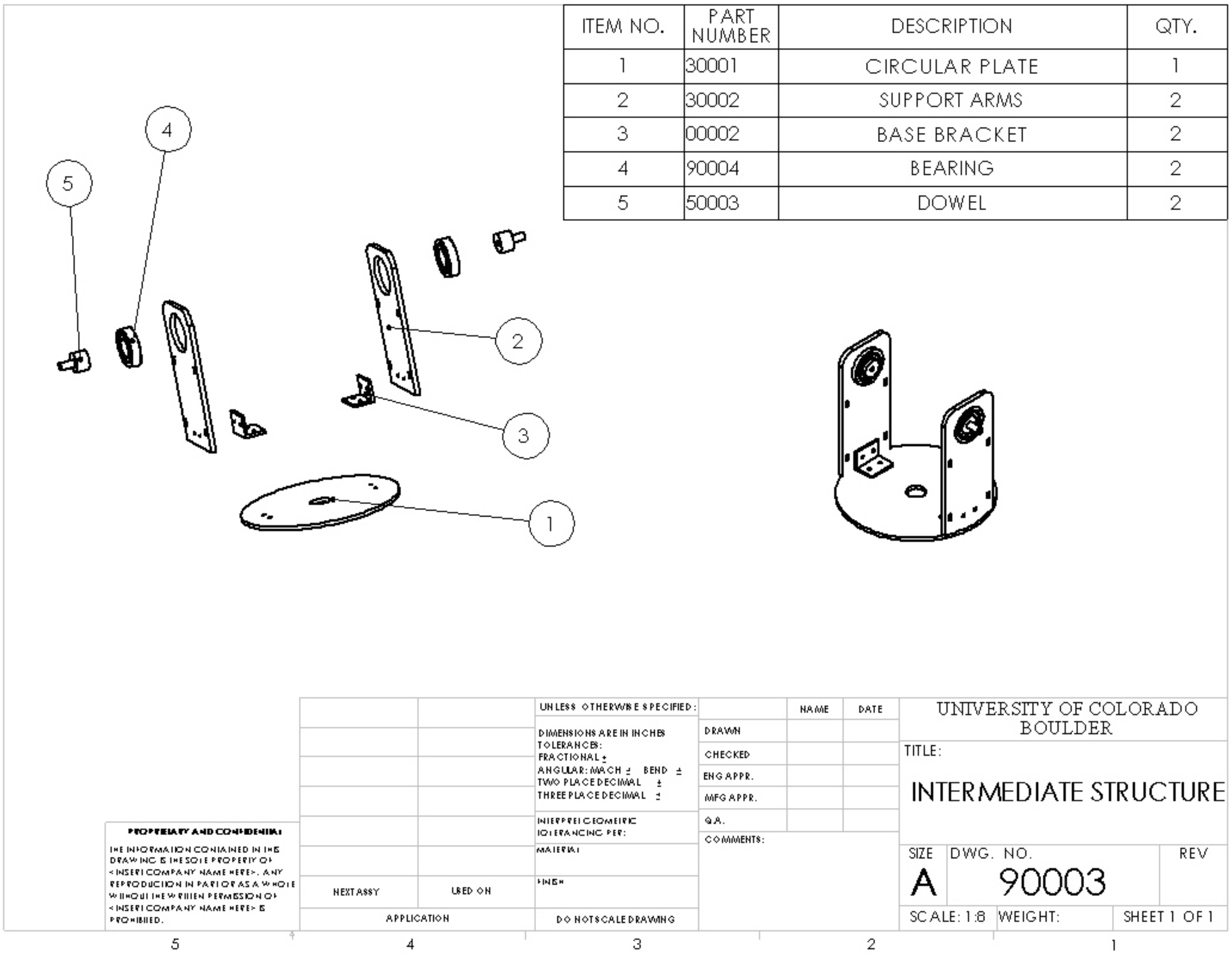
# Appendix



| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. |
|---|---|---|---|
| 1 | 20002 | CAMERA_HOUSING_SIDE | 2 |
| 2 | 20001 | CAMERA HOUSING BASE | 1 |
| 3 | 80002 | SCIENCE CAMERA | 1 |
| 4 | 80001 | ADCS CAMERA | 1 |

Figure 17: Camera Housing

## Preliminary Diagrams



| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. |
|---|---|---|---|
| 1 | 30001 | CIRCULAR PLATE | 1 |
| 2 | 30002 | SUPPORT ARMS | 2 |
| 3 | 00002 | BASE BRACKET | 2 |
| 4 | 90004 | BEARING | 2 |
| 5 | 50003 | DOWEL | 2 |

UNIVERSITY OF COLORADO BOULDER
TITLE:
INTERMEDIATE STRUCTURE
SIZE A
DWG. NO. 90003
REV
SCALE: 1:8
WEIGHT:
SHEET 1 OF 1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

| | NAME | DATE |
|---|---|---|
| DRAWN | | |
| CHECKED | | |
| ENG APPR. | | |
| MFG APPR. | | |
| Q.A. | | |

COMMENTS:

NEXT ASSY
USED ON
APPLICATION

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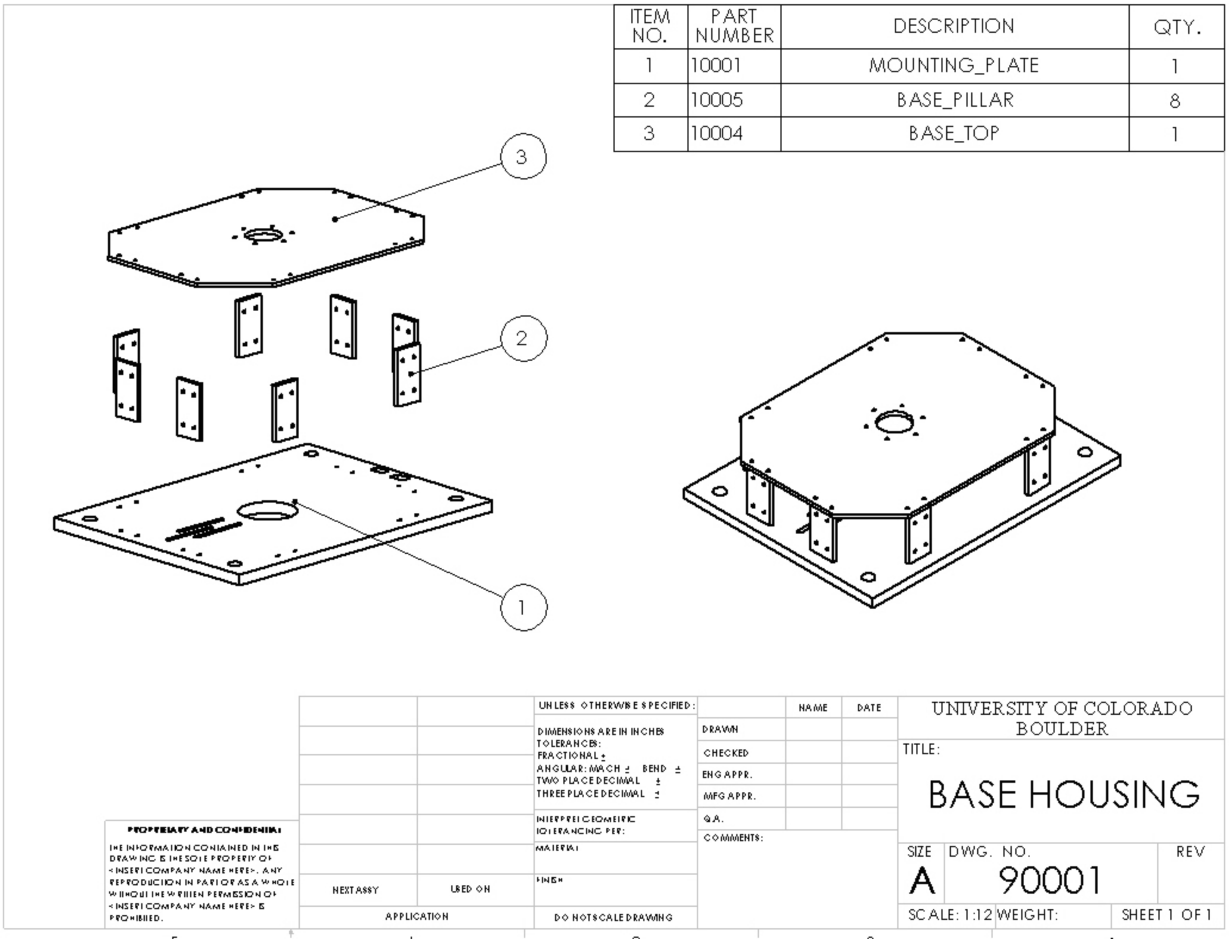
Figure 18: Intermediate Structure



| ITEM NO. | PART NUMBER | DESCRIPTION | QTY. |
|---|---|---|---|
| 1 | 10001 | MOUNTING_PLATE | 1 |
| 2 | 10005 | BASE_PILLAR | 8 |
| 3 | 10004 | BASE_TOP | 1 |

UNIVERSITY OF COLORADO BOULDER

TITLE: BASE HOUSING

SIZE: A
DWG. NO. 90001
REV
SCALE: 1:12
WEIGHT:
SHEET 1 OF 1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

NAME DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:

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Figure 19: Base Housing

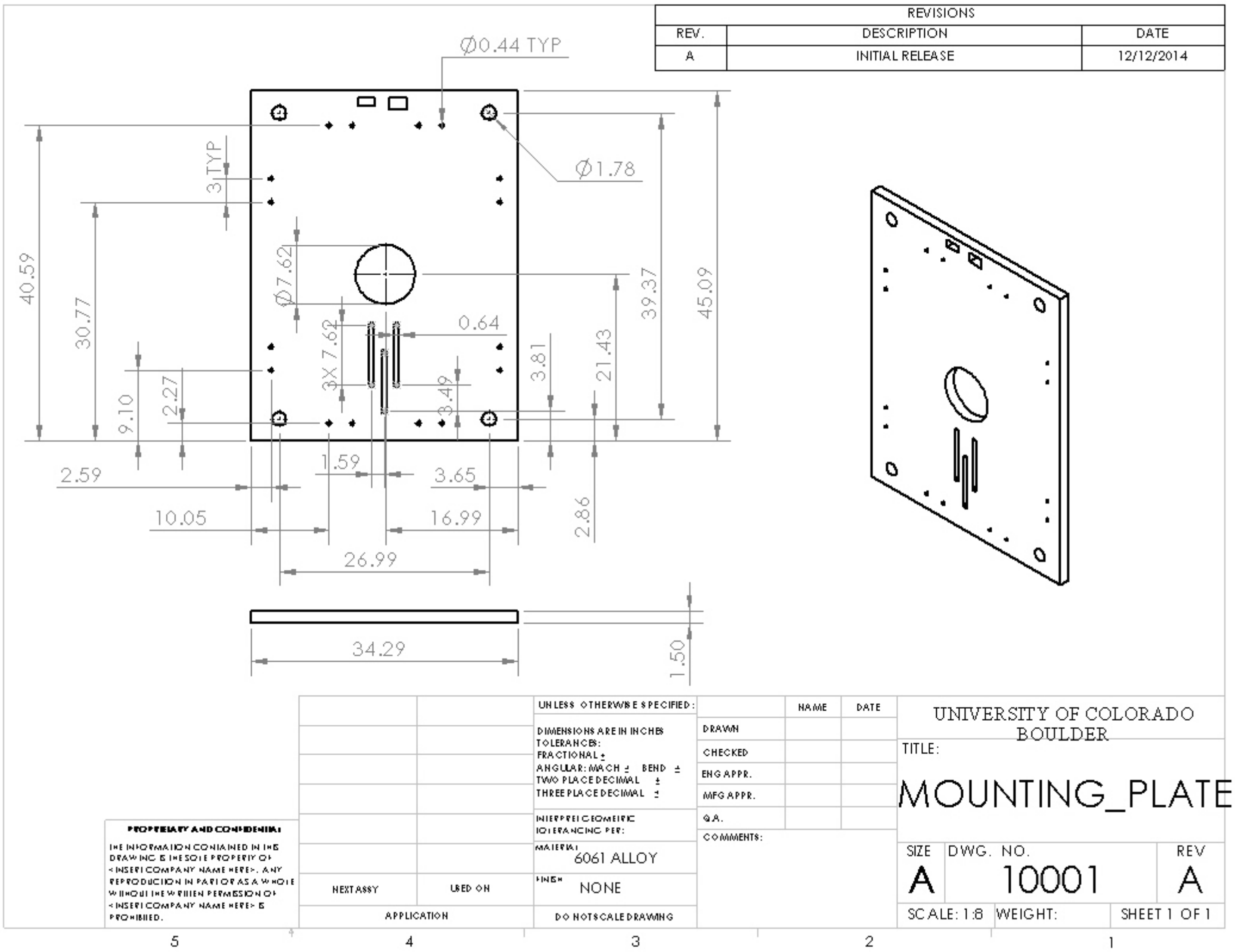

Figure 20: Mounting Plate

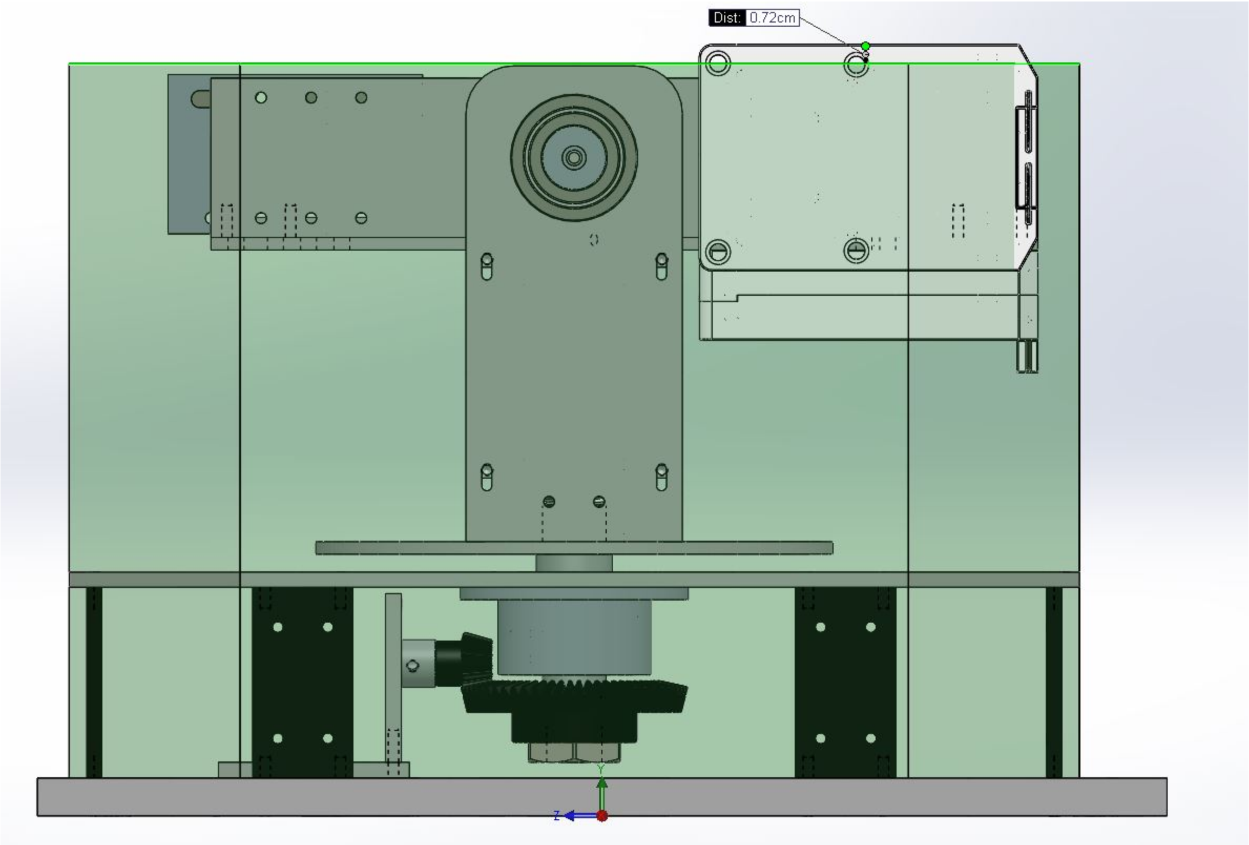

Figure 21: Resting Height

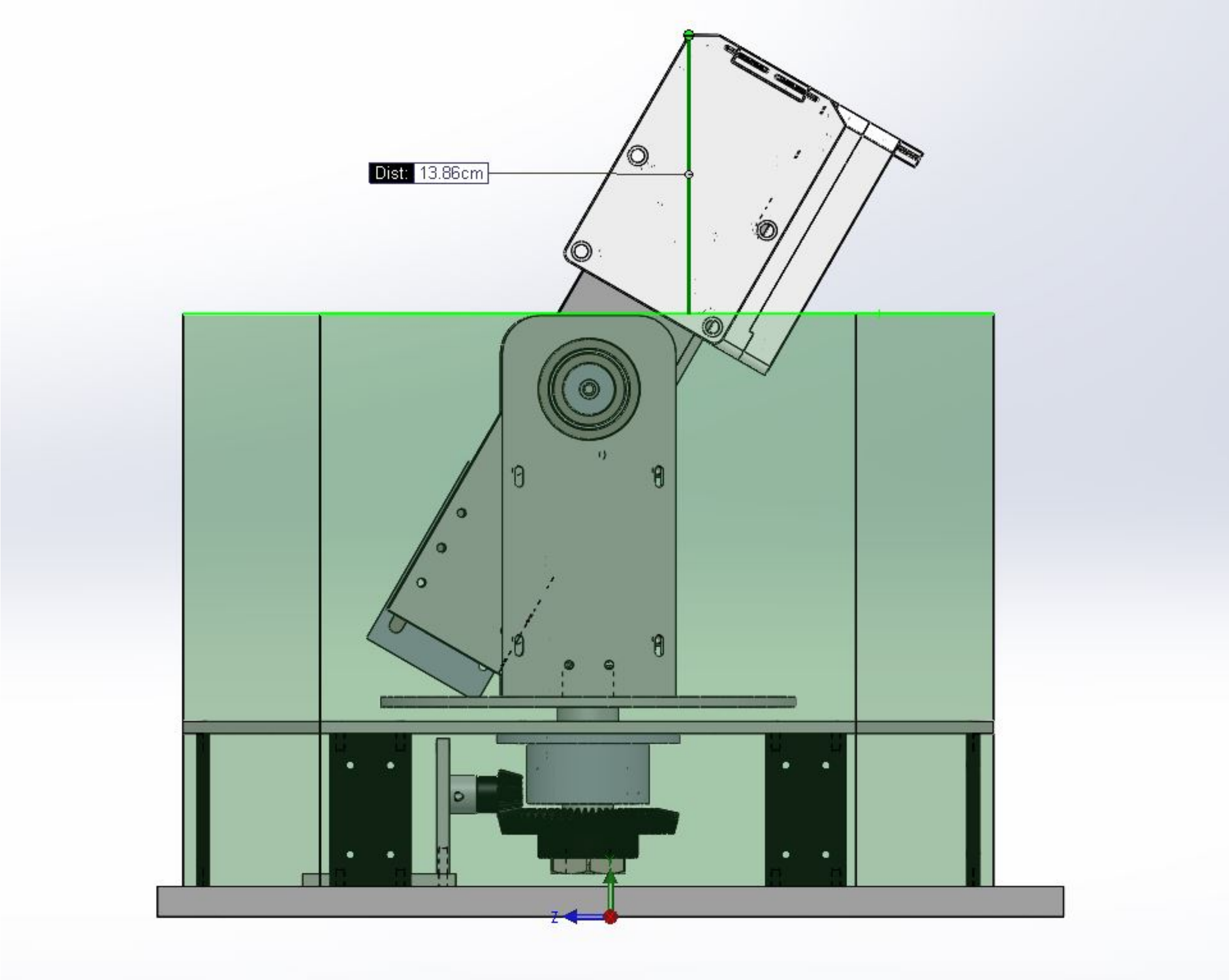

Figure 22: Extended Height

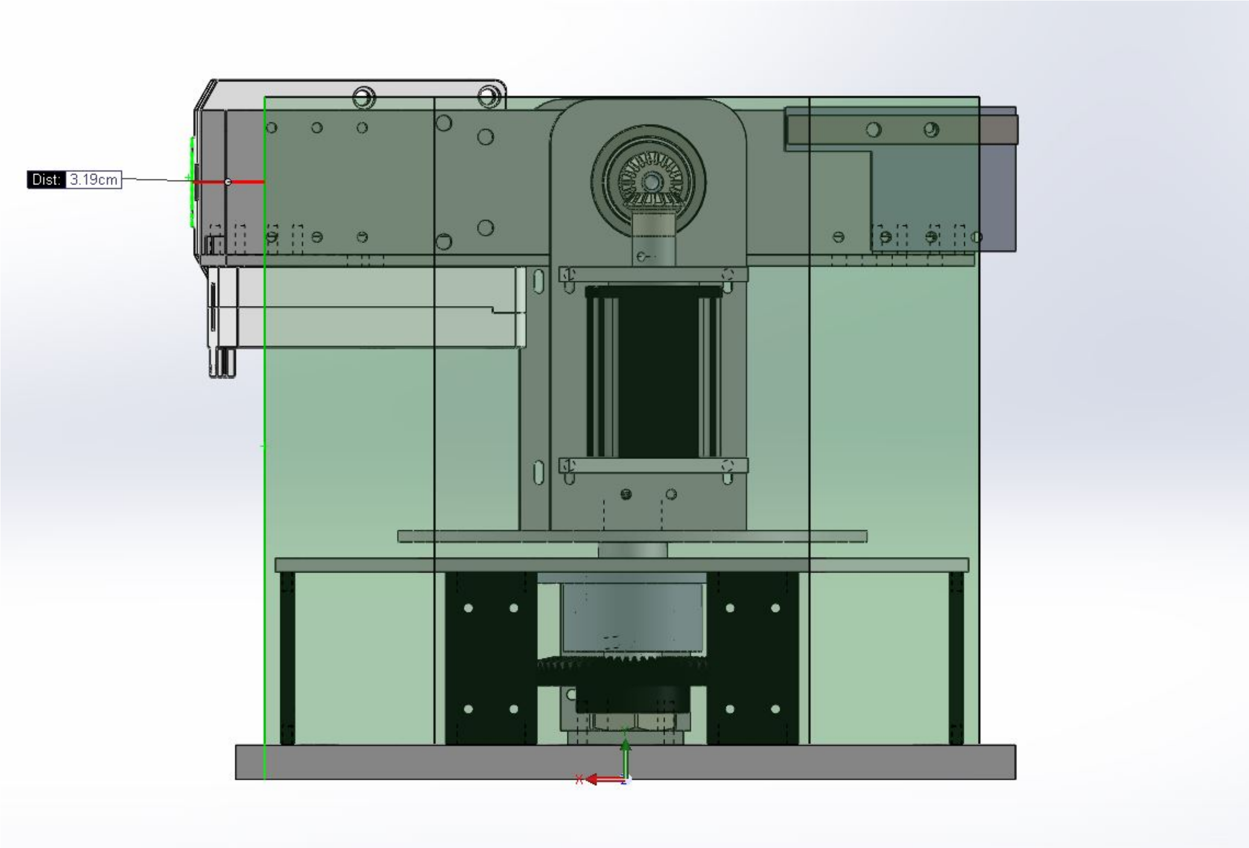

Figure 23: Width Envelope Resting

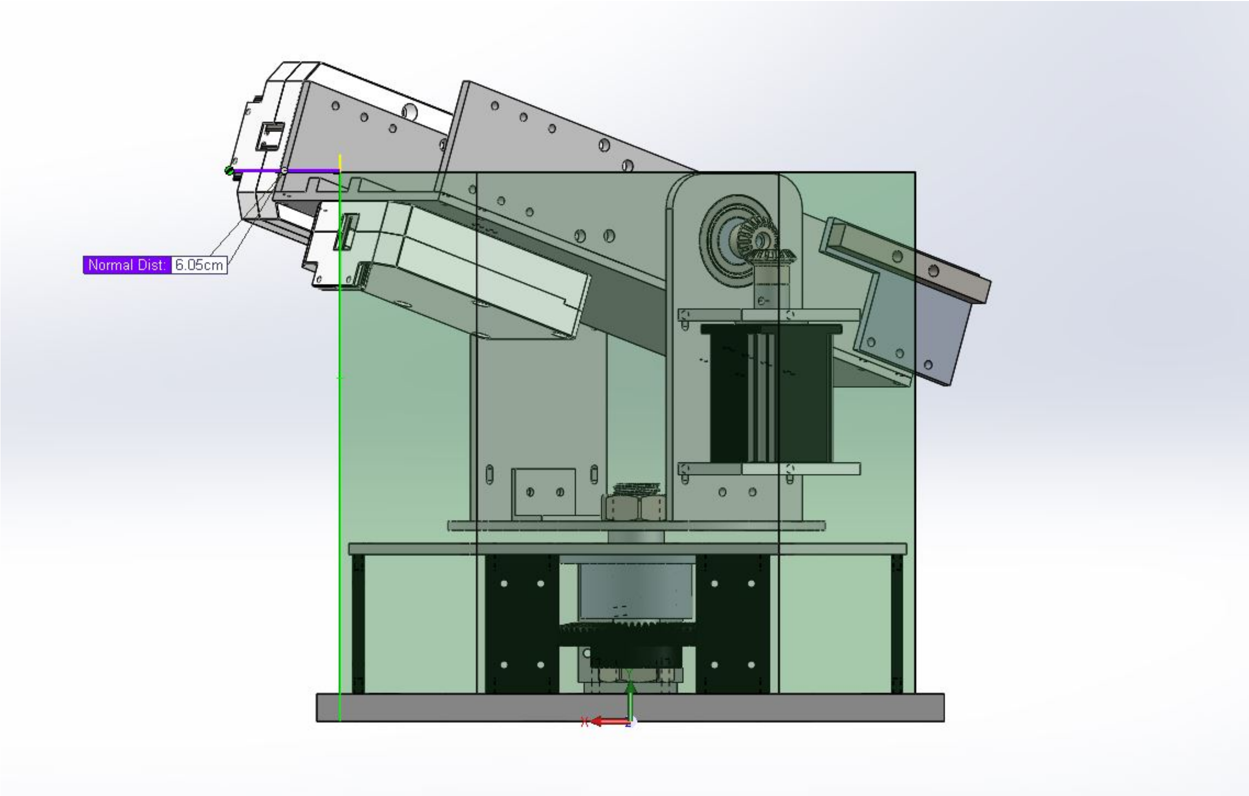

Figure 24: Width Envelope Maximum

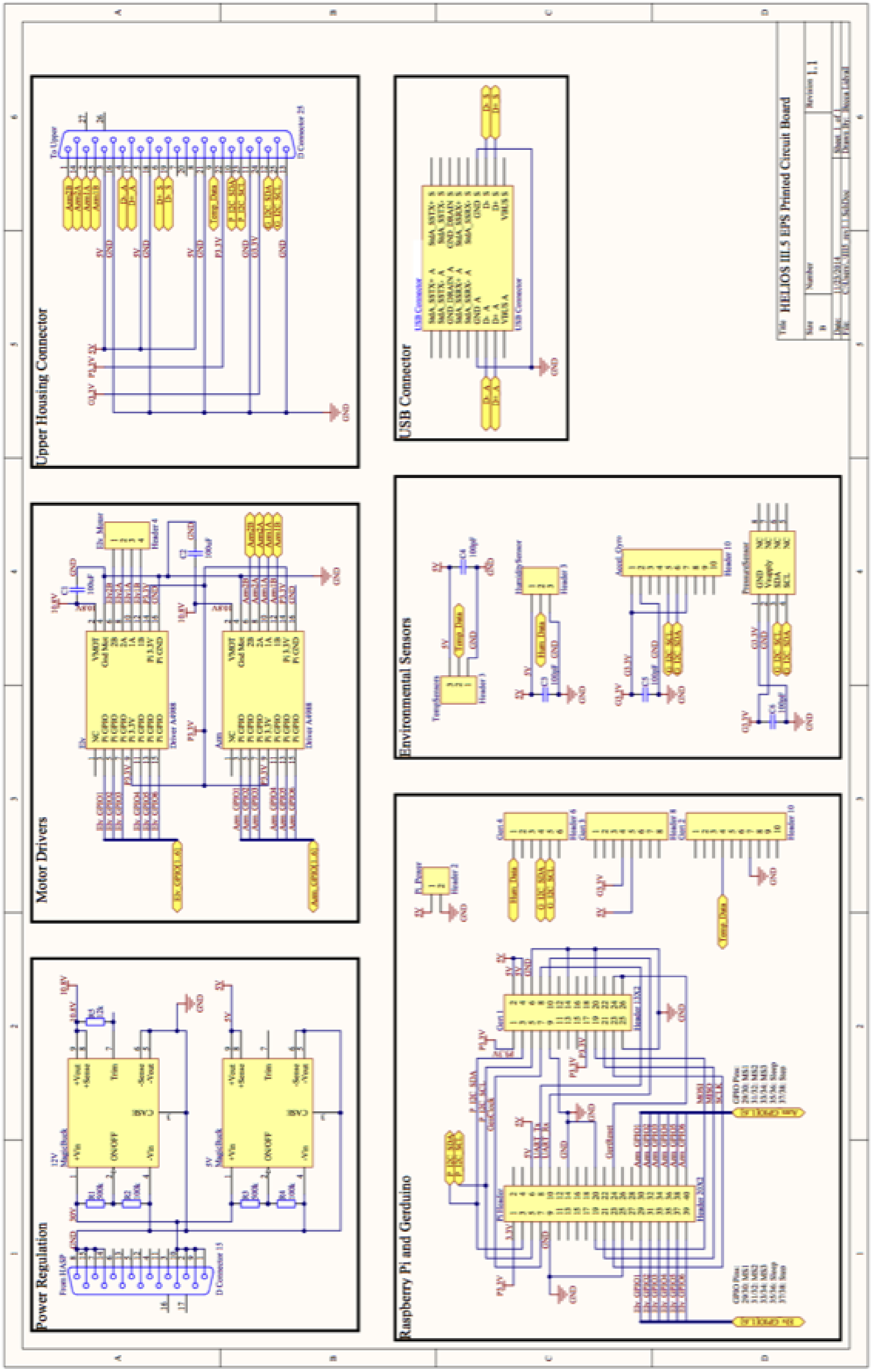

Figure 25: EPS PCB Schematic

# References

[1] Paige Arthur, Cooper Benson, Christopher Rouw, and Kristen Hanslik. The Potential for Solar Tracking and Observation On-board a High-Altitude Balloon Platform. April 2014.

[2] HELIOS III Team. Concept of design review. Presentation given at COSGC, February 2014.

[3] HELIOS III Team. Critical design review. Presentation given at COSGC, March 2014.

[4] HELIOS III Team. End of semester demonstration. Presentation given at COSGC, May 2014.

[5] HELIOS III Team. Final science presentation. Presentation given at COSGC, November 2014.

[6] HELIOS III Team. Preliminary data review. Presentation given at COSGC, September 2014.

[7] HELIOS III Team. Preliminary design review. Presentation given at COSGC, March 2014.