HASP Student Payload Application for 2016

Payload Title: Hydrogen-Alpha Exploration with Light Intensity Observation Systems V		
Payload Class: (check one) ☐ Small ☑Large	Institution: University of Colorado Boulder	Submit Date: Dec 18th 2015

Currently, solar observation is done either from the ground, where it is subjected to extensive atmospheric interference, or from satellites, which are extremely expensive. Observing the sun from a high altitude balloon platform mitigates almost all atmospheric interference at a fraction of the cost of actually placing a payload into orbit.

HELIOS V is a continuation of the University of Colorado's HELIOS missions. It will use the solar tracking system developed during the HELIOS IV mission to capture valuable science and engineering data. Its science objectives include capturing high quality images of the sun in the hydrogen-alpha wavelength to observe sunspots and possibly solar flares. Its engineering objectives include testing a star tracker for the potential of incorporating star tracking in future iterations of HELIOS's ADCS system, so that the payload can function during the entirety of HASP's flight.

The HELIOS V team will have a faculty mentor, but all other members of the team shall be undergraduate engineering students, including the project manager, systems engineers, and team leads.

If accepted and flown, HELIOS V will occupy a large payload spot, will draw the allotted 30 V from the HASP platform, and will utilize serial uplink and downlink.

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Hydrogen-Alpha Exploration with Light Intensity Observation Systems V

Colorado Space Grant Consortium

Proposal

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I. Mission

A. Mission Objective

The mission of HELIOS V is to use the HELIOS IV system to track and take pictures of the sun in Hydrogen-Alpha and to test a star tracker for the potential of future night-time tracking missions on HASP. HELIOS V is a continuation of previous HELIOS missions and will take advantage of previous missions' tracking success to gather science data.

Mission Objectives:

1. Take advantage of the HELIOS IV system to gather science data
2. Take images of the sun in the Hydrogen-Alpha wavelength
3. Test a star tracker for potential future night-time tracking

B. Mission Premise

1. High Altitude Balloon Observation

Currently the majority of solar observation is done either from ground based telescopes or orbiting space telescopes. These methods both have their drawbacks. Ground based systems have to deal with atmospheric interference, limiting the quality of observations or necessitating complex and expensive adjustments to account for this interference. Orbiting space-based telescopes operate without this atmospheric interference, but are extremely expensive to build and put into orbit. This severely limits the quantity of solar imaging missions in space. The lower quantity of orbital solar imaging missions in turn causes reduced access to the solar images taken by orbital observatories. With these restrictions in mind, an alternative method to observe the sun is through the use of high altitude balloon observatories. Solar observation from a high-altitude balloon platform such as the HASP platform has the advantages of being above 99.5% of the atmosphere where there is no interference while also being orders of magnitude less expensive than a space-based satellite.

The Colorado Space Grant Consortium (COSGC) at the University of Colorado, 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° 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, a team from COSGC and CU Boulder flew HELIOS I, a mission to test the viability of solar observation from a high-altitude balloon platform. The mission was mostly optics driven with two cameras designed to take pictures of the sun in Hydrogen-Alpha and Calcium-K wavelengths. The HELIOS II and III teams then improved upon this design in 2013 and 2014 by flying a similar mission that was more focused on the ADCS. Both payloads had several issues, prompting a HELIOS IV mission designed to improve upon them both and track the sun consistently. HELIOS IV was focused only on HELIOS's engineering mission of tracking the sun and not on its science mission, allowing for more time and effort to be dedicated to creating a robust tracking system. HELIOS IV functioned nominally throughout flight, tracking the sun consistently and taking an equivalent science image once every two seconds on average, thus proving the viability of solar observation on a high altitude balloon platform.

HELIOS V will take advantage the robust system developed by HELIOS IV to take high quality images of the sun in the Hydrogen-Alpha wavelength, thus fulfilling HELIOS's long-term science goals. HELIOS V also aims to to test a star tracker previously developed by the Colorado Space Grant Consortium's PolarCube team. This will assist PolarCube in characterizing their star tracker and will test for the potential of integrating a star tracker in future iterations of HELIOS's ADCS system. During the 2015 flight, the HELIOS IV payload functioned well during the day but could not gather any data after the sun set. Incorporating a star tracker would allow HELIOS to take full advantage of the HASP flight by allowing it to function throughout the entirely of flight.

2. Photometry

The optics system shall capture images in the Hydrogen-Alpha wavelength. What is considered visible light can be separated into two categories: light that is seen with the naked eye and appears in images as white light, or the filtered spectrum of this white light, which can be narrowed down to specific wavelengths. This filter system is used to observe details of the sun that would be obscured by the white light from the sun's photosphere.

H-alpha filters will allow the optics system to detect only a small bandwidth of visible light around the wavelength of 656.28 nm. This wavelength is absorbed and re-emitted by the hydrogen in the sun's atmosphere. It is one of the most useful wavelengths in which to observe the sun because it reduces the light from the photosphere, allowing for high visibility of solar features. This interaction between emitted light and hydrogen in the sun's atmosphere predominantly highlights surface features. Major solar features in this wavelength are solar prominences, sunspots, and coronal mass ejections. Therefore, H-alpha imaging of the sun provides incredible amounts of comprehensive data on solar activity.

The atmosphere of the Earth has shifting air pockets, which distort the view of ground telescopes despite scientific advancements in telescope design. The Earth's atmosphere has a considerable amount of hydrogen, despite its small percentage of the total composition. This hydrogen also interferes with ground-based solar observation. New ground telescope technology has been able to correct for the atmospheric distortion to some extent but there is not a way of seeing the wavelengths blocked by the atmosphere. Solar observation will achieve the best clarity only if it is done above the atmosphere.

C. Principle of Operations

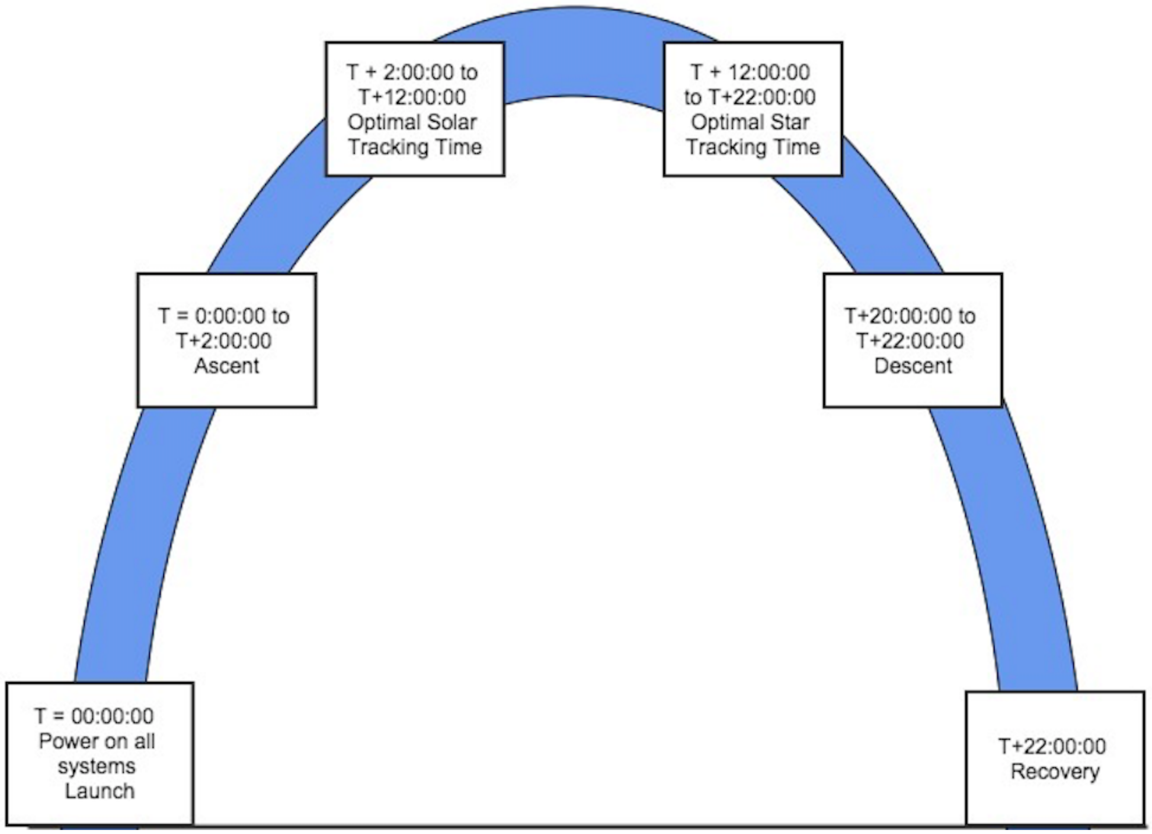

Figure 1: Principle of Operations Diagram

II. Mission Requirements

Level	Requirement	Derived
0	High Elevation Light Intensity Observation System (HELIOS) V shall have an optics system for capturing images of the sun	
1	HELIOS V shall fly a two-camera Star Tracker system for testing nighttime and daytime star tracker capabilities from a high altitude balloon platform	
2	HELIOS V shall utilize the HELIOS IV system to locate the sun and orient the optics system towards the sun on-board a HASP flight	

Level	Requirement	Derived
0.1	The HELIOS IV upper housing shall be redesigned to be able to house any future solar observation instrument(s)	0
0.2	An optics system shall be designed and implemented to capture images of the sun in Hydrogen-Alpha wavelength	0
0.3	A star tracker system shall be designed and implemented to characterize the ability to track stars from a high-altitude balloon and determine the viability of nighttime tracking operations	0
0.4	A high altitude balloon solar observation system shall be designed and implemented and shall utilize the HELIOS IV payload and its tracking system for a COSGC-sponsored HASP flight	0

Level	Requirement	Derived
0.1.1	The camera housing shall be physically large enough to hold any future solar observation instrument(s)	0.1
0.1.2	The camera housing shall contain the HELIOS IV ADCS Camera system	0.1
0.1.3	The camera housing shall accommodate the HELIOS IV photodiode housings	0.1

Level	Requirement	Derived
0.2.1	The CDH system shall allow for storage of captured images	0.2
0.2.2	The primary science camera of the optics system shall have a field of view no larger than 1.5° x 1°	0.2
0.2.3	The primary science camera system shall fly a Hydrogen-Alpha filter with a maximum bandwidth of 5 nm	0.2
0.2.4	The primary science camera system shall have a resolution (plate scale) equal to or smaller than the minimum angular resolution	0.2
0.2.5	The optics system shall be insulated and isolated from all other systems' thermal footprint	0.2
0.2.6	The optics system camera shall be compatible with the optics CPU.	0.2

Level	Requirement	Derived
0.3.2	The Star Tracker system shall characterize its survivability in intense sunlight conditions	0.3
0.3.1	The Star Tracker system shall capture images of the night sky and identify the portion of the sky imaged	0.3

Level	Requirement	Derived
0.4.1	HELIOS V shall comply with all HASP requirements outlined by the Call for Proposals and other LaSPACE documents	0.4
0.4.2	HELIOS V shall comply with all budget and schedule constraints dictated by COSGC and HASP	0.4
0.4.3	HELIOS V shall maintain a proper operational environment throughout flight	0.4
0.4.4	HELIOS V shall utilize the ADCS of HELIOS IV	0.4

Level	Requirement	Derived
0.1.2.1	The changes to the HELIOS IV camera housing shall not interfere with the functioning of the HELIOS IV ADCS camera system	0.1.2
0.1.3.1	The changes to the HELIOS IV camera housing shall not interfere with the functioning of the HELIOS IV photodiodes	0.1.3

Level	Requirement	Derived
0.2.2.1	The optics system shall have one camera with a resolution of greater than 1280 pixels x 720 pixels	0.2.1
0.2.3.1	The optics system shall remain below 60 °C throughout the flight	0.2.3

Level	Requirement	Derived
0.3.1.1	The sun-facing camera in the Star Tracker system shall capture and save images every 15 minutes during the day	0.3.1
0.3.2.1	The sky-facing camera in the Star Tracker system shall capture and save images every 15 seconds during the night	0.3.1

Level	Requirement	Derived
0.4.1.1	Payload volume shall not exceed 38x30x30 cm	0.4.1

Level	Requirement	Derived
0.4.1.2	Payload shall resist the effects of up to 10 g vertical force and 5 g horizontal force	0.4.1
0.4.1.3	Payload shall utilize a twenty-pin EDAC 516 interface to HELIOS IV system power and analog downlink channels	0.4.1
0.4.1.4	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	0.4.1
0.4.1.5	Payload shall allow serial downlink functioning at 4800 baud	0.4.1
0.4.1.6	Serial up-link shall allow for 2 bytes per command	0.4.1
0.4.1.7	Payload shall use a DB9 connector, RS232 protocol, with pins 2, 3 and 5	0.4.1
0.4.1.8	Payload shall transmit payload status to the HASP serial downlink	0.4.1
0.4.1.9	Payload shall be mounted according to the HASP platform interface requirements	0.4.1

Level	**Requirement**	**Derived**
0.4.2.1	All receipts and proofs of purchase shall be retained	0.4.2
0.4.2.2	Schedule shall include weekly deadlines for each phase of design, assembly, and integration process	0.4.2
0.4.2.3	Schedule shall include all design document revisions; including relevant presentations	0.4.2
0.4.2.4	Schedule shall contain weekly team meetings	0.4.2

Level	**Requirement**	**Derived**
0.4.3.1	The optics system structure shall be insulated to minimize thermal footprint of other systems	0.4.3
0.4.3.2	All systems shall remain within operating temperatures while experiencing external temperatures between -80 to 60 °C	0.4.3

III. Design

A. Optics

The HELIOS V optics system is composed of two cameras with separate objectives. The ADCS camera system is designed to track the sun's position. 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. In order for the optics system to complete its mission objectives, a telescope shall be flown in conjunction with the science camera. These two camera systems will be mounted parallel to each other in the camera housing.

1. ADCS Camera System

The ADCS camera has a small field of view compared to the GoPro flown on HELIOS IV, but a very large field of view in comparison to most scientific instruments. As such, it shall be used in a manner to support the success of HELIOS V by serving as the sun tracking camera. Equipped with a large field of view, the sun's image will be small enough for the ADCS camera to find the sun, as long as it's in the field of view, and to center the camera housing on the sun. Once the sun is detected in the field of view, HELIOS will rotate on elevation and on azimuth until the sun is brought to the center of the camera's image.

The ADCS camera system that shall fly on HELIOS V is the same ADCS camera system that flew on HELIOS IV. The camera is a See3CAM10CUG - 1.3MP Monochrome Camera, shown in Fig. 2 on the following page, that has a 1/3in CMOS sensor chip with a 640 x 480 pixel resolution (for USB 2.0), 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 1.4 million kilometers and the Earth is at an average distance of 150 million kilometers from the sun, resulting in an angular diameter of approximately 0.532° , or 1883″. This means the resulting picture on the CMOS chip will be 129 ″/px, or 95,911 km/px, based on the linear diameter of the sun being approximately 743.5 km/″. Due to the large amount of light intensity coming for the sun, it is important to ensure that the incoming light 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 0.0126% 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 electrical tape, and the camera lens is a standard C-mount thread.

2. Science Camera

The mission of HELIOS V is to perform the solar observation that HELIOS IV made possible. The pictures taken from HELIOS IV prove that solar observation is possible, but the camera flown on HELIOS IV cannot capture images with a quality high enough for the degree of observation that the HELIOS V team intends. By flying a telescope, the HELIOS V team shall capture high resolution images of the Hydrogen-Alpha emissions from the sun for the purpose of solar observation. Flying a telescope in conjunction with a camera, rather than flying a camera alone, will allow for the possibility of observing sunspots. The sun's 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. Prior HELIOS missions have used Hydrogen-Alpha as their primary science filter because it produces high resolution photographs of the sun which can even feature sunspots. 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 V science camera system. By using a a Hydrogen-Alpha filter, a high quality camera, and a telescope to replace the GoPro, HELIOS V will be able to capture quality images of the sun from the HASP balloon platform.

HELIOS V will be equipped with three filters and one focal reducer. Because the sun emits too much light for the camera's sensor to capture, filters will be needed to refine the range of wavelengths and the

Figure 2: ADCS Camera equipped with two neutral density filters

intensity of light that the camera's sensor is exposed to. The configuration of the filters, telescope, and camera is located in Fig. 3 on the next page.

The first of the three filters will be a neutral density filter, which will be responsible for absorbing a large portion of the sun's energy. The neutral density filter is the first part of the system to encounter light because it will limit the total amount of light in the system, and prevent other components from becoming damaged. A neutral density filter functions by evenly decreasing the intensity of the light that passes through it across all wavelengths.

This neutral density filter is critical to preventing damage to the telescope and camera chip. Without this filter the heat from concentrated sunlight could result in catastrophic damage, shattering mirrors in the telescope and overheating the camera chip, rendering the system inoperable. The neutral density filter will be responsible for absorbing the largest portion of the energy, and will have an optical density of no less than 3.0. This will protect the primary and secondary mirror from overheating and shattering. This will be placed over the primary aperture of the telescope.

After the neutral density filter has reduced the intensity of light in the system, the telescope then magnifies its subject. The telescope HELIOS V plans to use is the Orion Apex 90mm Maksutov-Cassegrain Telescope. The telescope is 254 mm in length, has an aperture of 90mm, and weighs 1.678 kg. It has a focal length of 1250mm, however this is later reduced by the focal reducer.

After light has exited the telescope, the next filter will be a longpass filter. It will be the first filter mounted on the camera structure, before any additional filters. This second filter will allow the energy from the concentrated sunlight to be further reduced to tolerable levels by narrowing the range of wavelengths

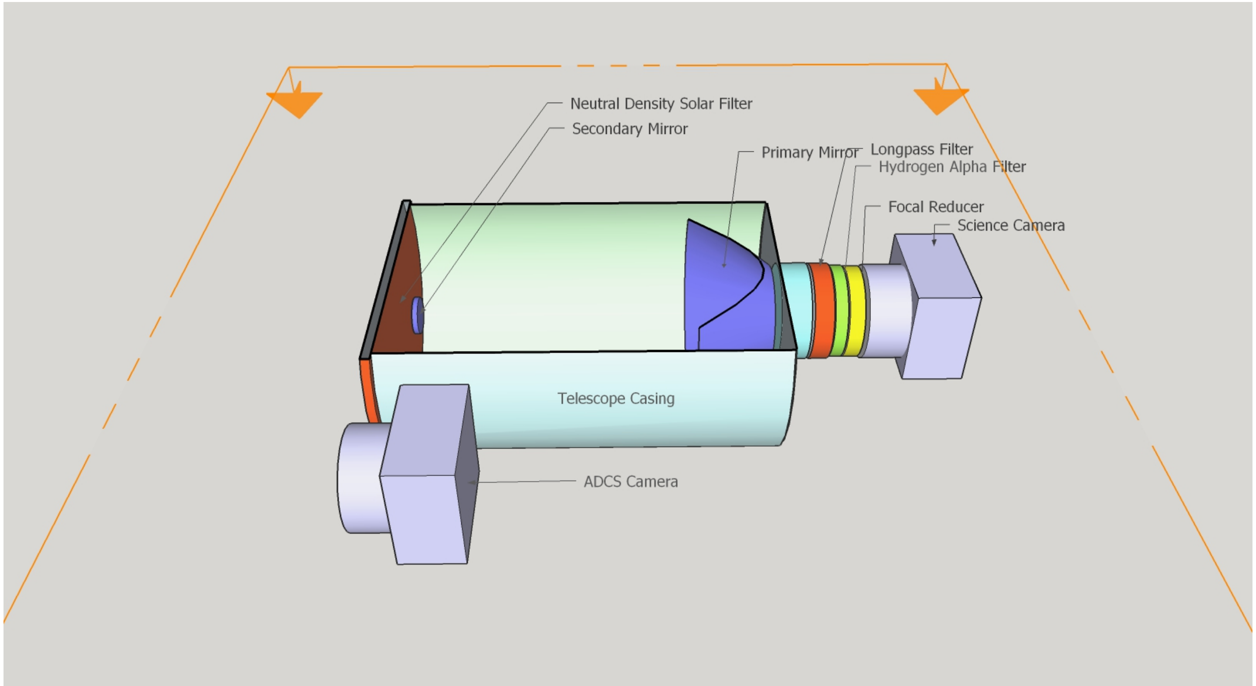

Figure 3: Configuration of science camera system.

that will be passed to the Hydrogen-Alpha filter. This filter will remove all light with a wavelength less than 600 nm, which is blue light. This is useful because blue light has higher energy than red light. Thus, filtering out all of the blue light will remove a lot of heat from the system.

Following the neutral density and longpass filters, a Hydrogen-Alpha filter will be used to filter all remaining light so that only light with a wavelength of 656.28 nm will be transmitted. The Hydrogen-Alpha filter the HELIOS V team plans to fly is the Astrododon 3 nm Hydrogen-Alpha Narrowband Filter. This filter has a bandpass of 3 nm and has a 1.25 inch mount, which allows it to easily attach to the camera.

Following this filter, a focal reducer will be used to allow the camera to view the sun's surface with less distortion at the edges. A focal reducer reduces the effective field of view of the camera, which will allow for an image that captures more physical area without changing the focal length of the telescope or the size of the camera's sensor. This will allow HELIOS V's telescope to capture the entire disk of the sun for observation. Using a focal reducer will also reduce the distance at which the camera must be placed relative to telescope, effectively reducing the size of the optics subsystem. The reducer used will be an Achromatic .44x combined focal reducer and field flattenner, which cuts the telescope's focal length by over half thereby more than doubling the field of view and reducing the focal length of the optics system from 1250mm to 550mm.

The camera is the final piece of the system, and its sensor records the image after the light has been filtered down to the hydrogen alpha wavelength. The camera that will be used will be the DMK 51BU02 camera manufactured by The Imaging Source. This camera features a global shutter and a 1/1.8" CCD sensor, with a 8.5mm x 6.8mm sensing area. This sensor shall provide the science camera system with a 0.885° x 0.708° field of view. Since the sun is approximately 0.532°, this shall provide a large enough viewing area to capture science images, even if the payload is slightly off centered. The camera has a C-mount, which will allow it to attach to the telescope and filters. The dimensions of the camera are 50.6mm by 50.6mm by 56mm and it weighs 265g. The camera will be powered by a USB 2.0. The camera captures images with 1620 x 1220 pixels. This camera was chosen because it has a mount that will easily attach to the rest of the equipment, will capture monochrome images of the sun in high resolution, and is powered in a manner that works with the current power system on the HELIOS payload.

As previously mentioned in the ADCS Camera section, the camera calculations proposed are based on the assumption that the angular diameter of the sun is approximately 1883″, with the linear diameter of the sun being approximately 743.5km/″. The physically limiting parameter of light, the minimum angular resolution for this science camera system is approximately 1.83″. This means that solar features must be at least 1360km apart on the surface of the sun, in order for this science camera system to tell them apart. Based on these assumptions, the resulting image from the science camera system displayed on the camera sensor will be approximately 1.65″/pixel, or 1227km/pixel. This resolution (plate scale) will be more than enough to observe all of the solar features that the minimum angular resolution will allow. For reference, sunspots range from about 1200km across to 50,000km across on average.

B. Star Tracker

As an aside from the core mission, the HELIOS V team seeks to determine the viability of a Star Tracker sensor for future missions. Up to this point, the durability of a Star Tracker in intense sunlight has not been tested and such a task can be accomplished on HELIOS V in a simple and unobtrusive manner to the central mission. Furthermore, since past HELIOS missions have only tracked the sun, tracking abilities were nonexistent during a large portion of the flight after the sun set. If the Star Tracker is successful on HELIOS V, it could be used on future missions for location determination during this previously unused time. HELIOS V's Star Tracker team shall partner with Colorado Space Grant's PolarCube, a 3U CubeSat, to integrate their working Star Tracker system into HELIOS V's upper housing.

HELIOS V shall fly two separate Star Trackers in HELIOS's upper housing, one lying flat on the rear counterweight and the other on the front face near the ADCS and camera lens. Star Tracker A shall be mounted on the top of the leftmost rear counterweight, facing vertically. The Star Tracker team will work in collaboration with the structures team to ensure proper placement of the system. Since HELIOS V will not collect solar data overnight during the flight, the upper housing can be programmed to an optimal angle for imaging. This angle would minimize glare and allow for a clear view of space. Star Tracker A will attempt to capture images of the night sky every 15 seconds and using an algorithm, will identify the portion of sky imaged in-flight and downlink this data to the ground.

The Star Tracker algorithm requires at least four stars to begin its identification process. The Star Tracker searches for bright stars in its field of view, finds four or more stars, and is able to calculate the angles between each using triangles with points at three of the stars. The specific angles match with specific stars, which is how the Star Tracker identifies the portion of the sky imaged. Success of the Star Tracker will be based on its accuracy of identification and will give the team a clearer understanding on its potential for use in future tracking missions. In order to save power and prevent interference with HELIOS V's current sun imaging system, Star Tracker A will be powered off during the day–HELIOS V's main operation time.

The second Star Tracker, Star Tracker B, will be used to test the conditions and durability of the Star Tracker when facing directly at the sun. Star Tracker B will do no actual tracking for the mission; tracking will be accomplished with the successful ADCS system from HELIOS IV. However, before the team can potentially use a Star Tracker on future missions, it must be made certain that the Star Tracker can withstand sun exposure. To achieve this, the HELIOS V team plans to run Star Tracker B until failure, if not the entire flight, and assess the quality of images taken throughout its lifespan. Images shall be taken every 15 minutes and saved for further analysis. The current dimensions of the front face of the upper housing allow for Star Tracker B to be mounted directly on the front face. The Star Tracker's lens will face in the same direction as the ADCS lens in order to ensure maximum sun exposure. Before being implemented in the payload, Star Tracker B will be tested extensively from the ground. If the Star Tracker cannot survive sun exposure from the ground, the team will remove it from flight for it will not last in an far more intense near space environment. In gauging failure of the Star Tracker aboard HELIOS V, there will be either a depreciation of the quality of images captured by the Star Tracker or the complete failure of the sensor.

The Star Trackers proposed for this mission, as pictured in Fig. 4 on the following page, consist of three major components: the Tracker itself, a lens assembly, and an interfacing shield. The Star Tracker is a 3.25 in by 1in board and the shield it connects to is 4.5 in by 2.125 in. HELIOS V's Star Tracker shall utilize USB data protocol as the communication method between the board and processor. The Tracker will be powered by a 5V power connection and the nominal current draw of each Tracker should not be more

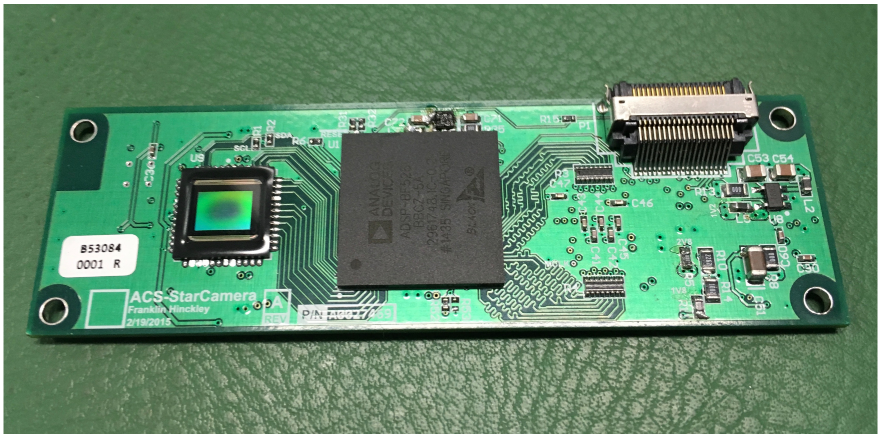

Figure 4: Star Tracker

than 330mA. The status of the Star Tracker will be downlinked to the ground as well as stored in HELIOS V however photos from the Star Tracker will not be downlinked. See CDH section for further details.

C. Structures

The HELIOS V payload consists of three major structures, the base housing, the intermediate structure, and the camera housing. 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 is made up of a custom baseplate, structural pillars, and a top plate, both shown in Fig. 5 on the next page. The HELIOS IV team manufactured a custom baseplate primarily for its enhanced thermally conductive capabilities, as will be discussed later. The baseplate provides a heat sink for the EPS board and the motor drivers, as well as a ground source for the EPS board. HELIOS V will use this baseplate once again, as it was proven to be effective by HELIOS IV. Pillars are used for support because they are light and easy to machine, especially as compared to a truss support system. The base housing contains the main EPS Power Board, the azimuth motor, the Raspberry Pi, and the main axle. It provides grounding connection for the EPS board. The top plate has been modified to minimize mass without compensating structural integrity. Thermal blanket will cover the holes created in the top plate of the base housing to continue to protect the internal components.

The camera housing consists of a bottom plate and two side plates, and provides the mounting locations for the two photodiode housing, shown in Fig. 6 on page 15. It houses the ADCS Camera and the science camera, as well as the Star Tracker devices.

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 compromised 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 and axles, which are 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.

To ensure enough torque is provided by the azimuth motor to rotate the intermediate structure and camera housing in the azimuth direction, a 4:1 gear ratio is used on the azimuth axis. The elevation axis is completely balanced, and a 1:1 gear ratio is used to transfer the plane of rotation from the motor to the elevation axis.

To ensure proper gear alignment and meshing, slots are cut into the base plate to provide a way to adjust the contact ratio of the gears. Holes are also cut into the arm of the intermediate structure to allow for vertical motion of the motor shown Fig. 16 on page 35, which provides a way to adjust elevation gears in order to obtain the correct gear contact.

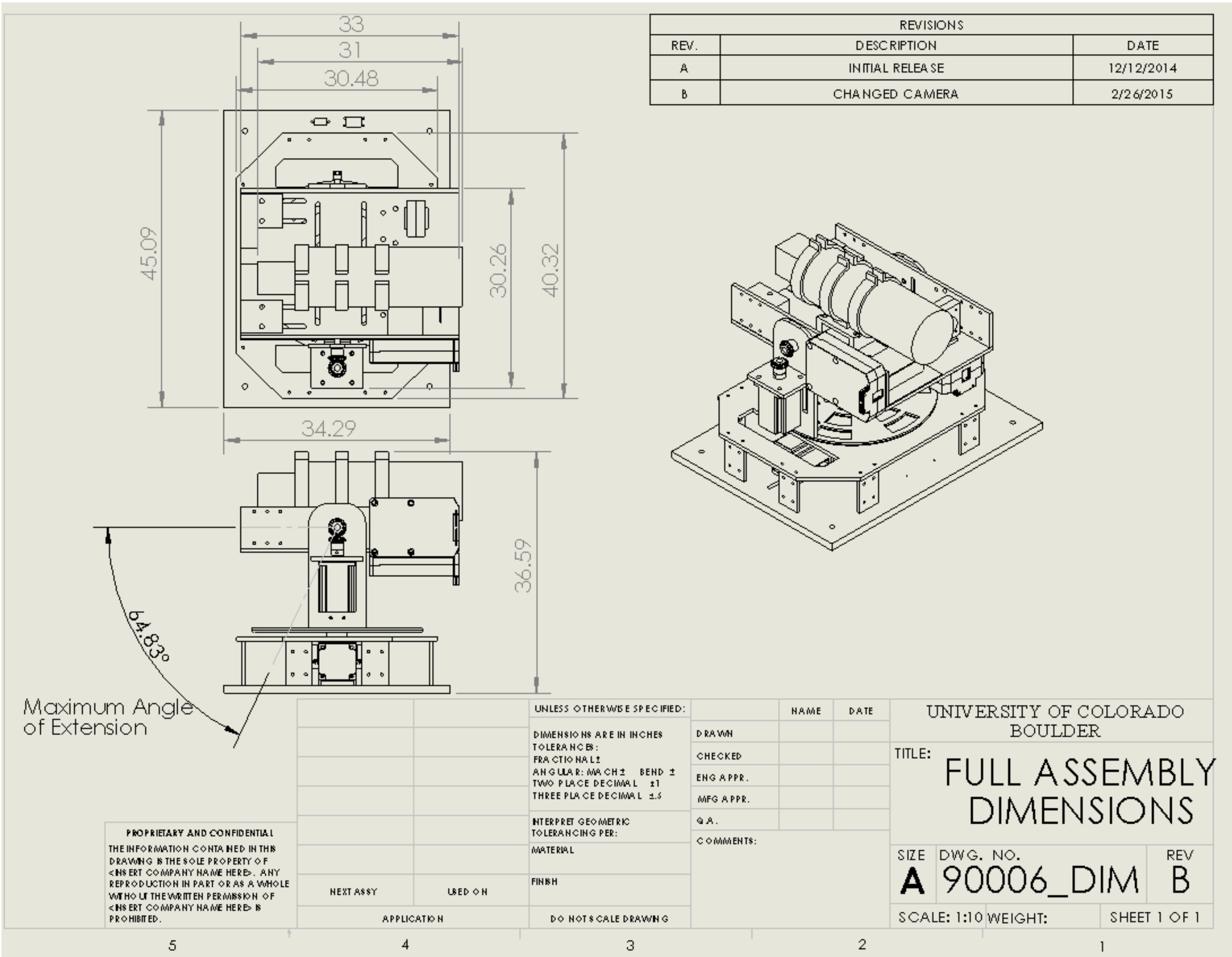

Figure 5: Full Structural Assembly (units in cm)

Another necessity of the structure for the ADCS to function properly is the correct balancing of the camera housing. A dual axis slotted weight system is implemented to provide balance adjustment of the camera housing. It consists of a large counterweight in the back of the camera housing to adjust the horizontal balance, and a counterweight connected to the elevation axle on the opposite side of the elevation motor in order adjust the vertical balance of the camera housing. The rear counterweight has been split in half, to allow the telescope adequate mounting room, and the elevation counterweight has been decreased in mass slightly since HELIOS IV. This was made possible by moving the center of mass of the camera system. The center of mass of the camera systems is now less erratic, as the telescope mounting assembly is movable. Capable of sliding in two dimensions, the assembly allows for adjustments to the heavy telescope and center of mass as the weight of the telescope varies. This allows for interchangeable telescopes and other science instruments. The horizontal counterweight will be better secured so that it does not fall at any time during shipping to flight or flight integration, as it did on HELIOS IV.

The azimuth axle has threaded ends for large nuts to screw onto and secure both the large azimuth gear and the intermediate housing. A through hole is drilled in the axle for wires from the EPS board and Raspberry Pi to run up to the camera housing, minimizing wire tangle. The structure is easy to assemble and disassemble, with threaded holes in both sides of the base housing pillars.

In order to accommodate the new observational tools and Star Tracker, the upper bus of HELIOS V will be widened slightly from its predecessor. This will allow for the bus to accommodate the wider telescope and

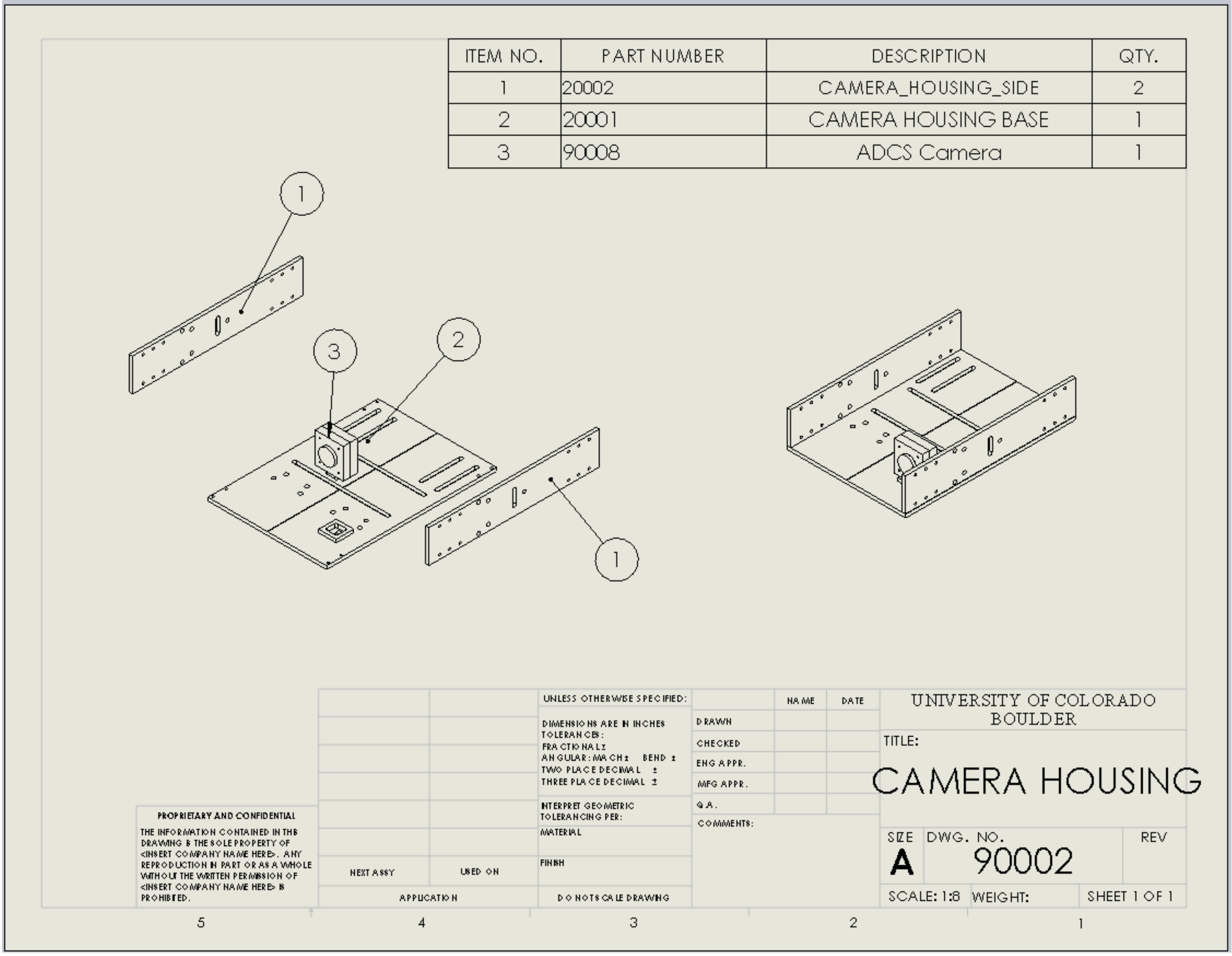

Figure 6: Upper Housing Assembly (units in cm)

science camera of HELIOS V, as well as leave more room for interchangeable instruments on the structure. The top of the base housing, and circular disk on the mount assembly. The circular mounting plate will have symmetrical holes cut in a hex configuration and the base plate will also have two cuts on the sides, to reduce weight of the whole system. The height ceiling also has to be increased by 6 cm from the previous HELIOS structure. The counter weight in the back will be split into two, one on each side on the back, in order to make room for the new telescope. Including the telescope and excluding the 5 kg base plate, the weight of the assembly is currently 15.267 kg.

The telescope stand is an adjustable slider on the camera housing base made of 6061 aluminum alloy. The holder that connects to it is made of rigid PVC plastic and is interchangeable with different sizes of holder to accommodate different sizes of telescopes and science instruments.

1. Structural Integration

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

D. ADCS

The primary task of the ADCS is to locate the sun in the sky and orient the camera housing towards the sun. The attitude of the camera housing shall be determined by utilizing two photodiode arrays attached to it, and image analysis by the ADCS camera. The photodiode array on the right of the camera housing shall detect the light along the y-axis or the elevation, while the array on the bottom of the camera housing shall detect the light along the x-axis or azimuth. The Raspberry Pi shall collect the photodiode readings and run image analysis on the image camera data to determine how far off from the sun the camera housing is. The Pi will then command the stepper motors to move the camera housing one step closer to being centered on the sun.

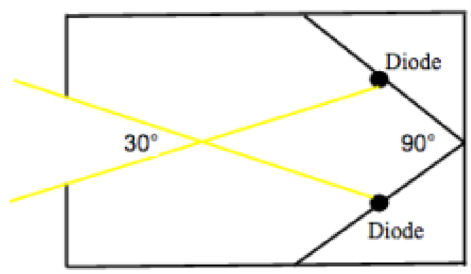

Figure 7: The positioning of the photodiode inside the photodiode housing

The photodiodes alone are not precise enough to center the housing on the sun. The two system control solves this, as the ADCS camera can make the fine tune adjustments necessary for accurate solar tracking. Diode readings and image analysis together shall be used to center on the sun to the required precision.

For the precision tracking, the ADCS algorithm shall perform image analysis on photos from the ADCS camera. Until the sun is in the range of the ADCS camera, the photodiode arrays will be controlling the motor. Once the sun is in range of the ADCS camera, then the ADCS camera will feed the Pi to issue the commands with one motor to move the camera housing in azimuth, and the second motor to move the camera housing in elevation. The Pi will command the motors to rotate the camera housing until the ADCS Camera images 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 IV. The only changes shall be minor improvements to the motor code, specifically involving microstepping, to make the system turn more smoothly. The image analysis code shall also be tested more thoroughly to determine any changes that can be made to it to improve the precision of the system. The commands, such as nudging, will also be made more robust. Sun tracking will be accomplished with the photodiode arrays and the motors used for the HELIOS IV flight, on both azimuth and elevation simultaneously.

1. Photodiode Arrays

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 A. 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 ADC 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. One photodiode array will read light intensity on the azimuth, while the other array shall measure the light intensity on elevation. Each photodiode array shall contain two small diode boards

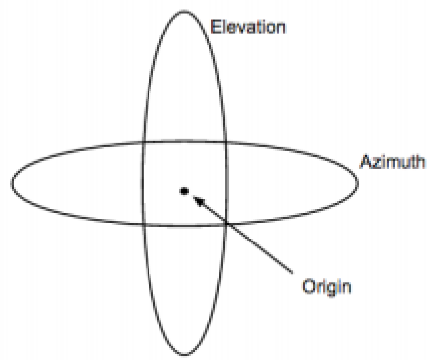

Figure 8: Elevation and Azimuth

and each board will contain two photodiodes, one primary diode and one backup diode, for a total of eight photodiodes in the system.

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 maximum 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 Fig. 7 on page 16. 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 Fig. 9 on the next page.

2. Image Analysis

During flight, HELIOS IV downlinked the results of its image analysis and saved pictures to its internal storage. Over the course of the flight, over 34,700 images were captured by the camera that contained the sun. A successful Science Image (one in which the sun was centered to within a reasonable science instrument's field of view) was captured on average once every two seconds. Image analysis returned the center of the sun in terms of degrees off from the center of the image. This provided a large source of data about the effectiveness of the payload's tracking system. The same image analysis process will be used with data from HELIOS V due to the positive results gained from HELIOS IV.

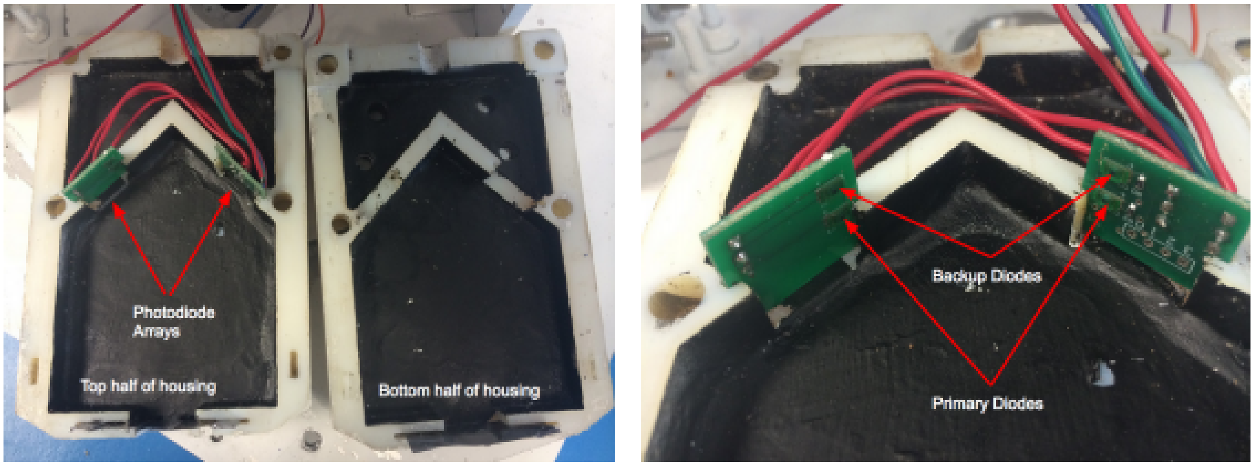

Figure 9: Internal Photodiode Array

3. Stepper Motors

Two stepper motors will be used to move the camera housing by rotating it in azimuth and elevation. The motors are bipolar motors with 200 steps per revolution that take 3.2 V at 2.8 A. Two identical stepper motor drivers will be used to control the motors, and the Raspberry Pi microprocessor will send commands to the drivers. The drivers will be used to power the motors and will receive 10.8V of power from the EPS board. The drivers have a built in current controller that allows the drivers to run with up to 2 A, although current above 1.2 A requires heat sinks in order to not overheat the drivers.

The drivers will allow the motors to micro-step. Sixteenth-step micro-stepping will be used, allowing the motor to move 3200 steps per revolution. With the four to one gear ratio on azimuth, the azimuth motor will be able to move 12800 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 0.028 13° on azimuth. The motors are capable of rotating the optics system by 3° per second.

4. Control Algorithm

The ADCS Control algorithm consists of a dual main flight loop, with several manual and automatic commands to respond to various situations encountered during flight. The control algorithm for the ADCS system works by first checking if the sun is in the field of view of the ADCS camera. The sun's orientation will be recorded in elevation and azimuth every seventh of a second. If it is not in the FOV (as will almost certainly be the case first upon activation/launch), then the photodiode system will take control until the sun is in range. Once the sun enters the field of view of the ADCS camera, the image analysis algorithm will take over. The ADCS system is controlled based on three data inputs: i) numerical readings given by the image analysis code; 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 and elevation; 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 Fig. 10 on the following page.

5. 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 12 bit binary numbers, in the form of the difference in readings

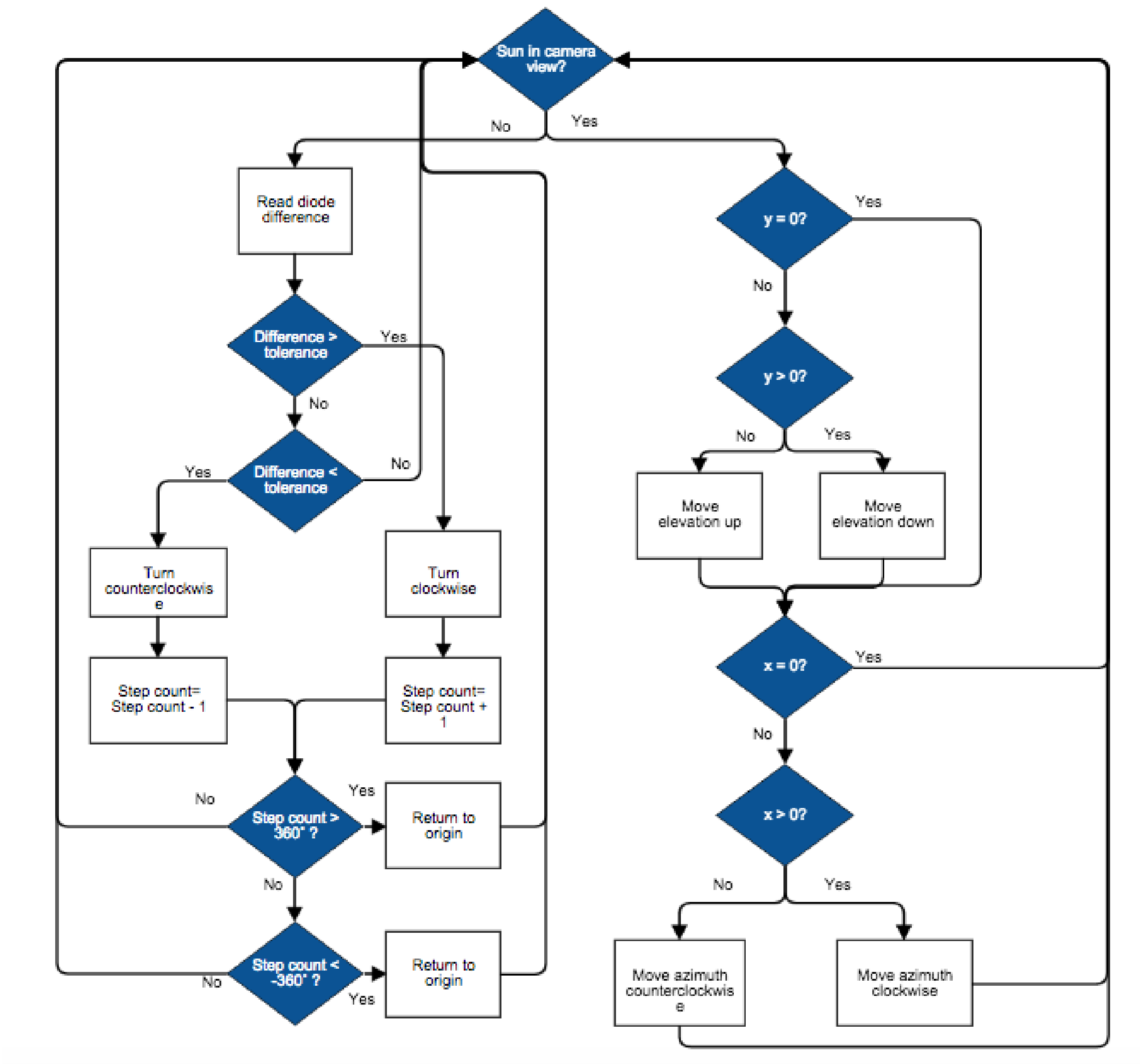

Figure 10: ADCS algorithm

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 are the inputs for the photodiode code used to control the motors up until the point at which the sun comes in range of the ADCS camera. At that point the ADCS camera image analysis code takes control of moving the unit precisely to center on the sun.

The diodes will constantly read voltage drop, and the ADC have a sampling rate of 6Hz. Therefore, the model will be able to give a value for degrees needed to turn the motors every 1/6th of a second. This is due to the fact that the model will give one value of degrees needed to turn for every one value of diode reading.

6. *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 one.

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 sixteenth steps, corresponding to 0.1125° 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 0.028 13° . 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 origin. This prevents damage to the payload by ensuring the wires from the bottom of the payload to the top do not become tangled or pulled loose if the payload were to spin too far in one direction.

For movement in elevation, the motor driver will be set to have the motor take sixteenth steps, as it does in azimuth. The system takes eight sixteenth steps at a time as this method has been proven to be most smooth. The motor will be connected to the system via a 1:1 gear ratio, so the number of degrees taken per step will be 0.1125° . This means that 360° or one revelation is equivalent to the motor taking 1600 steps in either direction. Once the system turns 60° upward, or approximately 530 steps, the algorithm will restrict further upward rotation to prevent the housing from trying to turn further than it is structurally able. The same will occur if the camera housing tries to turn below 0°.

7. *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 V will be able to be clearly seen from this video feed. The data received from this video feed is qualitative. Nudge commands will be implemented that allow the HELIOS V team to manually turn the camera housing by any amount if it is visually observed that the payload is pointing too far away from the sun for the photodiodes to detect any light.

8. *Test Procedure*

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 and during various times of the day. It will be subjected to reflections and shadows to ensure it is robust enough to recover from distractions. Image analysis will be tested thoroughly, since that was the part of the ADCS that had the shortest testing time during HELIOS IV development.

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 eld of view, the system 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, 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.

E. EPS

HELIOS V shall receive 30V DC from the HASP platform. Two DC-DC buck converters shall be used to immediately step down the voltage from 30V to 12 and 5V. A simple trimming resistor will be used to bring the 12V line down to provide the correct 10.8V 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.

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 46.77W. Because the voltage from the HASP platform is 30V, the maximum current draw from the platform is 1.56A. This is well under the maximum current limit of 2.5A and will not be a risk. Since most of components from HELIOS V are already working together and implemented in the schematic, relatively minor changes are needed to add the new components. Currently, HELIOS V EPS will have the same printed circuit board as the HELIOS IV mission since it was successful and the new components can be easily connected to it.

The new components include the two Star Trackers which shall be connected to the main PCB board for power. The Raspberry Pi Zero shall also be connected to the main PCB board for power to 5V and ground and to the already implemented Raspberry Pi to collect data from the CMOS Monochrome Camera. The CMOS Monochrome Camera will be connected to the Raspberry Pi Zero via USB.

Table 2: Power Budget

Component	Voltage(V)	Current(A)	Power (W)
Raspberry Pi	5	1.1	5.5
Raspberry Pi 0	5	.16	.8
Elevation Motor Driver	10.8	1.2	12.96
Azimuth Motor Driver	10.8	1.2	12.96
ADCS Camera	5	.75	3.75
CMOS Monochrome Camera	5	1.5	7.5
Star Tracker	5	.33	1.65
Star Tracker	5	.33	1.65
Total Power			46.77

F. CDH

The CDH system aboard HELIOS V 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 2 microcontroller and a Raspberry Pi Zero, and flight code written in Python. The Raspberry Pi Zero is a new addition from the previous HELIOS iteration to help with the increased processing necessitated by the Star Tracker and science instrument. Upon the iteration of HELIOS V, the code efficiency will be optimized and the communication will be more efficient and robust.

1. Raspberry Pi

The Raspberry Pi shall be the main component in the CDH design, controlling communications with the platform, capturing ADCS images, and supporting the ADCS subsystem. The Raspberry Pi shall be connected to the photodiode arrays and motor drivers and shall control sun tracking. It shall also be connected to the HASP platform using a RS232 to USB converter for serial communications and to the ADCS camera using USB 2.0. In order to handle this variety of goals, the Raspberry Pi shall run flight software that shall be separated into distinct threads. This allows the threads to run concurrently on the processor without allowing one thread to use all of the processing power.

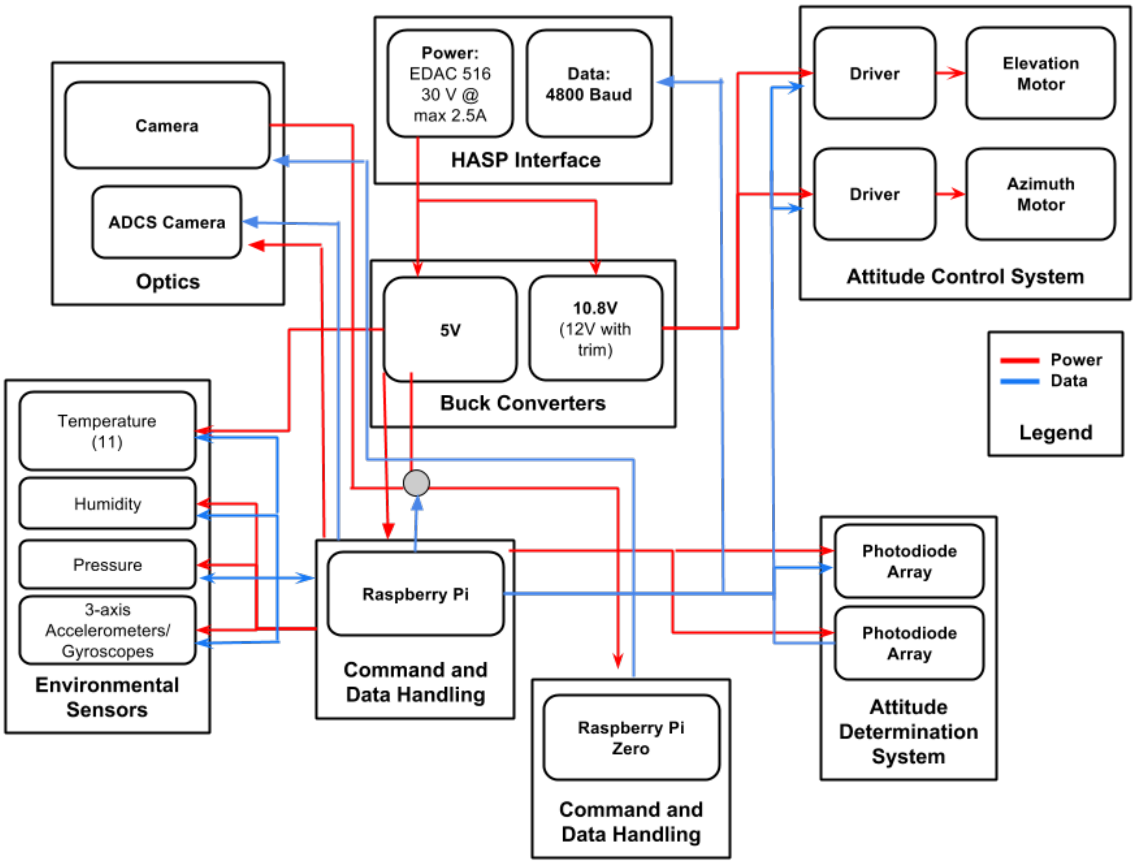

Figure 11: CDH FBD

2. Monitoring Commands from Ground

The uplk thread will be responsible for awaiting two-byte serial commands uplinked by the ground station. It shall idle until it detects data in the serial buffers, and then it passes the relevant information to the threads affected. If any issues are detected with the uplinked command, it shall downlink an error to the 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 will downlink an acknowledgment. The thread will then idle until more data is uplinked to the payload. The HELIOS V 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.

3. Downlinking Data to Ground

This thread will process and downlink data from the other threads to be sent to ground. The payload shall allow serial downlink functioning at 4800 baud. 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 page 24, along with some of 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 350bit/s, and no analog downlink channels will be used.

Table 3: Command Table (*variable integers representing amount to rotate in degrees)

Payload Command	Two Byte Hex Command	Description
Ping	0xAA 0xAA	Ping the payload to test communications
Pan mode on Pan mode off	0xBB 0xFA 0xBB 0xFB	Toggles panning mode for total diode failure
Toggle diode pair - phi Toggle diode pair - theta	0xBB 0xA1 0xBB 0xA0	Toggle between main and backup diodes
Azimuth Nudges	0xC0 0x00-0xB4* 0xC1 0x00-0xB4*	Negative Nudge Positive Nudge
Elevation Nudges	0xD0 0x00-0x41* 0xD1 0x00-0x41*	Negative Nudge Positive Nudge
Raspberry Pi Zero on (default) Raspberry Pi off	0xEE 0x0A 0xEE 0x0B	Toggles power to the Raspberry Pi in the upper housing
Night Mode on Night Mode off	0xFF 0x0A 0xFF 0x0B	Changes ADCS from sun tracking to star tracking mode

4. Sun Tracking

This thread is the most expansive and resource intensive and shall analyze all pictures taken on the ADCS camera through image analysis or diode readings in order to provide direction for both the azimuth and elevation motors. In the case that the sun is too far out of the range of the ADCS camera's lens, the diode-analysis function shall take the difference of the two diode's readings and adjust the azimuth and elevation accordingly. In the case that the ADCS camera is capturing the sun within its images, an outside function shall be called to locate circles within the image, in this case the sun, and the azimuth and elevation shall be adjusted according to the distance of the circle from the center of the image. The ADCS thread shall be handled on the Raspberry Pi 2 and its goal is to track the sun.

5. Sampling Data

The sens thread shall sample data from each sensor, including the status of the new Star Tracker system, and record such data in a package for downlinking to the ground station via the HASP platform. In addition, the sens thread shall handle any commands necessary for operation of the Raspberry Pi Zero. This thread is the simplest of the four threads and shall be handled on the Raspberry Pi 2 as well. The goal of sens is to handle the data on-flight and to control power to the Raspberry Pi Zero. It will both save data to the SD card at a high rate and downlink data to allow the team to analyze system health during flight.

6. Raspberry Pi Zero

A Raspberry Pi Zero will be responsible for saving pictures directly from the science and star cameras in the upper housing of the payload. It will save image data to its internal SD card via USB 2.0. The purpose for using a second Raspberry Pi solely connected to the camera is to minimize changes to the original and successful code of the primary Raspberry Pi as well as avoid burdening the Raspberry Pi 2 with additional tasks. I2C communication will be used to command the Raspberry Pi Zero. Using I2C communication will allow the EPS board and structure to have minimal changes to support the additional processor. If the Raspberry Pi Zero encounters an issue, it shall be rebooted manually. With a transistor, the power shall

Table 4: Downlink Data Format

Bytes	Content	Example
0	Start Header	0x01
1-3	Payload Identifier	CU
4-6	Payload Identifier (cont.)	HE
7-9	Thread Identifier	PI
10-12	Record Type	EX
13-26	Timestamp[a]	1400019944.34
27-29	Length of data	13
30-40	Adler32 Checksum	-71889546
41	Start Transmission	0x02
42-(N-1)	Data	Sample Packet
N	End Transmission	0x03

default on and the Raspberry Pi Two will be able to block power to the Raspberry Pi Zero in order for it to restart.

G. Thermal

To ensure that no components overheat or 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 be wrapped around the outer perimeter of the bottom housing. All remaining exposed aluminum on the payload will be painted with white appliance epoxy to achieve high emissivity.

In order to heat sink components, an alternative to the standard base plate shall be used. 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 baseplate used will be the same baseplate flown on HELIOS IV.

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 heat sinked to the aluminum baseplate. A configuration utilizing thermal gap filler shall be used to interface between each of the buck converters and the baseplate. This process was followed for HELIOS IV, and worked well. This should not change for HELIOS V.

IV. Management

A. Team Organization

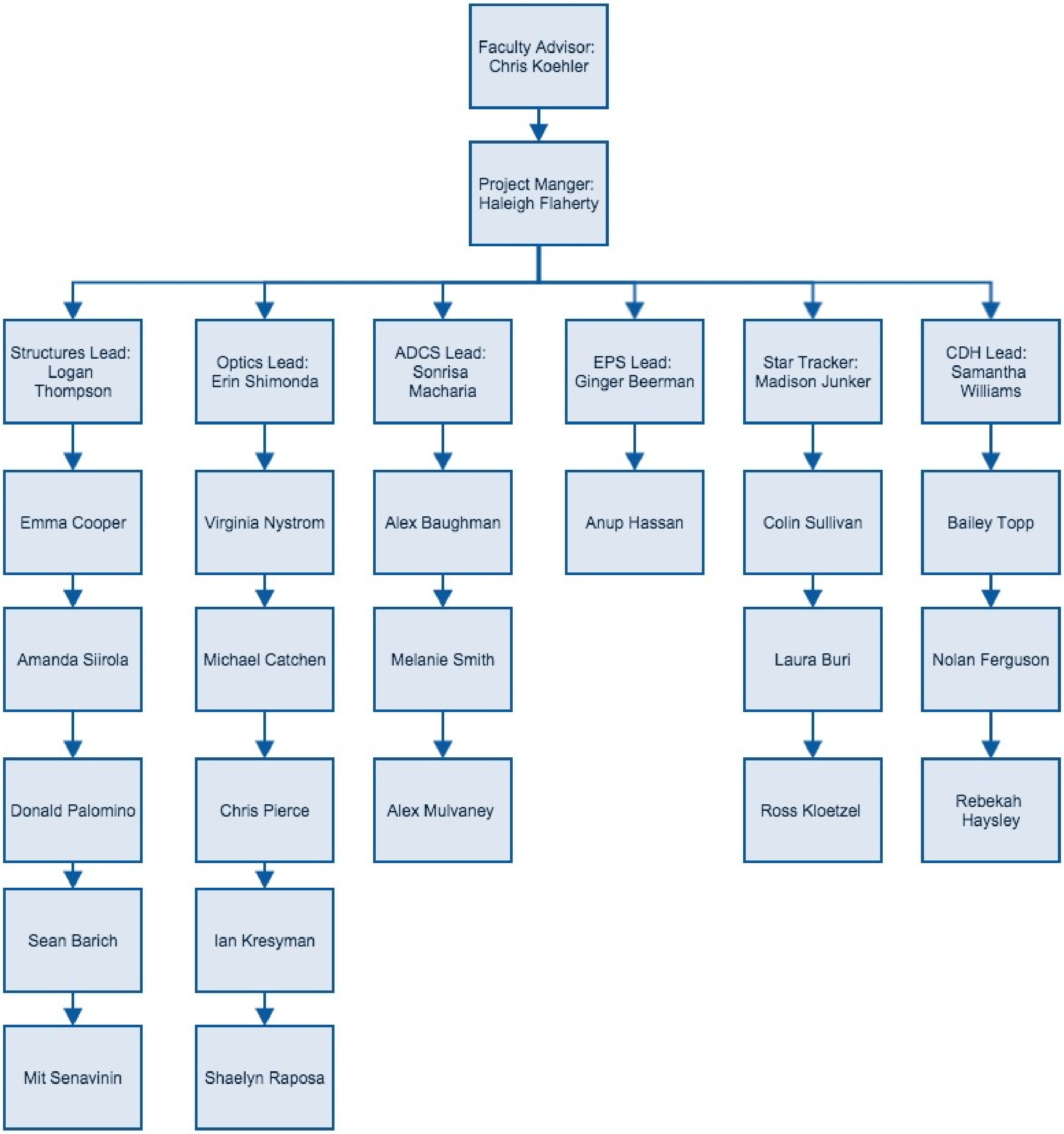

Figure 12: Team Organizational Chart

B. Schedule

Table 5: Schedule

Milestone	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Submit Proposal	X												
Officially Form Team		X											
CoDR			X										
Choose Science Camera			X										
PDR				X									
Create Nominal Case Telescope				X									
Finalize Design				X									
CDR				X									
Modify EPS Board					X								
Setup Pi Zero					X								
Finish Machining						X							
Integrate all Systems							X						
PSIP Due							X						
Systems Testing							X	X					
FLOP Due								X					
Integration in Palestine									X				
Flight										X			
Data Analsysis										X	X	X	
Final Science Report Due													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
ADCS Camera	0.138	1	0.138
Orion Telescope	1.678	1	1.678
Longpass Filter	0.040	1	0.040
Neutral Density Filter	0.227	1	0.227
Hydrogen Alpha Filter	0.040	1	0.040
Science Camera	0.265	1	0.265
Focal Reducer	0.025	1	0.025
Startracker	0.050	2	0.100
Raspberry Pi	0.043	2	0.086
Base Plate	5.055	1	5.055
Base Pillars	0.032	8	0.304
Base Top Plate	1.648	1	1.648
Circular Plate	0.594	1	0.596
Support Arms	0.245	2	0.490
Brackets	0.018	2	0.036
Camera Base Plate	1.217	1	1.217
Camera Side Plates	0.347	2	0.694

Component	Weight(kg)	Quantity	Total Weight(kg)
Ring Clamp	0.134	1	0.120
Telescope Stand	0.116	1	0.116
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	0.312	1	0.312
Elevation Axle	0.018	1	0.018
Shaft Extension	0.043	2	0.086
Flanged Hub	0.134	1	0.134
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			18.543 ± 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 V 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 V payload. The System's Engineer shall test all communication processes and equipment throughout integration to assure proper function. The following is a detailed integration plan HELIOS V 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) Power on and let run through start-up
    (b) Determine that sun-tracking capability is functional
    (c) Check SD card to ensure the system captured images from both cameras
    (d) Use switch to ensure ADCS does not attempt to rotate the motors during T-VAC

(e) Repeat steps a-c

4. Deliver payload to be weighed and have serial communication capability confirmed
5. Deliver payload to be integrated on the platform
    (a) Weigh payload to confirm it is under weight restrictions
    (b) Attach payload to test stand and power on
    (c) Confirm payload powered on and is downlinking data
    (d) Take payload to be structually integrated to the platform
    (e) Ensure payload powers on and downlinks data from the platform
6. Complete thermal vacuum testing
    (a) Look in data packets for startup notification downlink
    (b) Data is downlinked from the payload and the following can be seen in the data logs:
        i. Photodiode readings (from both azimuth and elevation arrays)
        ii. Accelerometer readings
        iii. Gyroscope readings
        iv. Temperature readings
        v. Pressure sensor readings
    (c) Confirm that graphs of downlinked sensor data made during T-Vac show nominal results. Confirm that graphs of downlinked environmental data taken by the payload approximately correspond with graphs of environmental data taken by the HASP platform.
    (d) Uplink to payload the command 0xAAAA which will ping the Raspberry Pi as documented in the uplink commands table. Look for response from payload in the downlinked payload data.
    (e) Monitor temperature of components as they should not fall outside of nominal ranges.
7. After T-Vac, re-enable ADCS control of motors

The team would prefer that HELIOS V be integrated in the same location as HELIOS IV 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 V 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

HELIOS V will send four to five team members to New Mexico with the payload. Unless the weather permits an imminent flight, the team representatives will likely leave New Mexico after HELIOS is successfully integrated onto the platform. Experience from HELIOS III and IV has lead the HELIOS team to conclude that it is not necessary to have the team in New Mexico during flight, as monitoring from Colorado has proved adequate. However, as previous payloads have suffered damages from shipping, the HELIOS team has concluded that it is necessary to have someone ensure that the payload is delivered and integrated intact.

The following is an approximation of flight times, altitudes, and events. The leftmost column are estimated times. 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 V payload on the HASP Platform.

Time	Task	Instructions	Indication of task completion
Upon arrival	Ensure gears are correctly aligned	Rotate housing 360 ° on azimuth and then approximately 50 ° on elevation.	Structure rotates without excessive resistance
Upon arrival	Camera housing properly balanced	Ensure that counterweight is in correct position to aid tracking system.	Housing will rest at correct angle
Upon arrival	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.
Upon arrival	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.
Upon arrival	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.
Upon arrival	Uplink, Telemetry, and Sensor check	Power on payload. Run though uplink commands.	Both telemetry (includes nominal sensor data) and acknowledgment received by mock ground.
Upon Arrival	Payload Tracking Capability	Power on payload. Allow payload to run for a 5 minute period of time. Then check both ADCS and GoPro images on micro SD card.	Payload orients the camera housing towards the sun. Image of sun is in majority of GoPro and ADCS pictures.
Upon integration	Ensure successful integration	Confirm that the payload is structurally and electrically attached to the platform and is turning on and downlinking when powered on	Visual confirmation that payload is secure and powers on when instructed
T = -1 hours	Remove lens caps	Remove the lens caps from the ADCS camera.	Visually observe that the lens cap is not on the camera.
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 ≈ 12 hours (sunset)	Switch to night mode	Send command to switch from solar observation to star tracker testing	Ensure acknowledgments are in downlinked data and visually observe that payload behaves as expected, turning downward and facing away from other payloads

VIII. Special Requests

1. Height and Width Extension

The primary reason for requesting the height and width extension is to accommodate the incorporation of the telescope. In order to capture any sort of solar observations, the aperture of the lens being used (or light collecting device) must be rather large. This is an optical feature of physics called the Minimum Angular Resolution. Larger apertures result in better images. This is why large diameter telescopes are very common in solar observation from both ground observatories and satellites, like NASA's SOHO satellite. HELIOS V would like to fly a telescope in order to prove the viability of high quality solar observation from a balloon platform. If any solar features are to be observed during the HASP flight, a telescope is needed in order to collect enough light to distinguish small features on the sun's surface. Although the inclusion of the telescope will breach the permitted static boundaries for the payload, the resulting Science Images will be far superior than any of the other HELIOS missions' camera systems. The HELIOS missions were designed to capture high quality images of the sun from a high altitude balloon platform. The only means with which to capture images of the quality that would provide valuable science data is a telescope like the one proposed. HELIOS V could fly a smaller instrument, but there would be very little point in doing so since better quality images could be taken from the ground, defeating the purpose of HELIOS.

HELIOS IV implemented a pin that would prevent the structure from turning on elevation during the thermal vacuum testing to ensure that HELIOS would not hit the top of the chamber. However, upon visual inspection of HELIOS in the chamber, it was determined that this pin was not necessary as even at it's full dynamic height of 43.28 cm, HELIOS IV was still short enough to not pose a threat of hitting the chamber. Thus, HELIOS IV was run in the thermal vacuum chamber without the inhibit, and did not hit the top of the chamber. The same inhibit pin can be implemented on HELIOS V, and with a static height of 36.59 cm, it will not even come close to posing a threat of colliding with the thermal vacuum chamber given the Gondola remains the same height as in the previous year.

2. 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 payload's 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

HELIOS V shall build upon the success of previous HELIOS missions by utilizing the tracking system developed during the 2015 mission to gather valuable science and engineering data. The HELIOS missions were originally designed to capture high quality images of the sun in the Hydrogen-Alpha wavelength to observe sunspots and other solar phenomenon. Now that a reliable tracking system has been developed, HELIOS V will return to that science and aim to capture high quality solar images. HELIOS V will also collect engineering data on a star tracker, which it will fly to test for the potential of incorporating into future iteration's of HELIOS's ADCS system, thus allowing HELIOS to take full advantage of the entirety of the HASP flight should it continue after the sun sets.

Appendix

A. System Diagrams

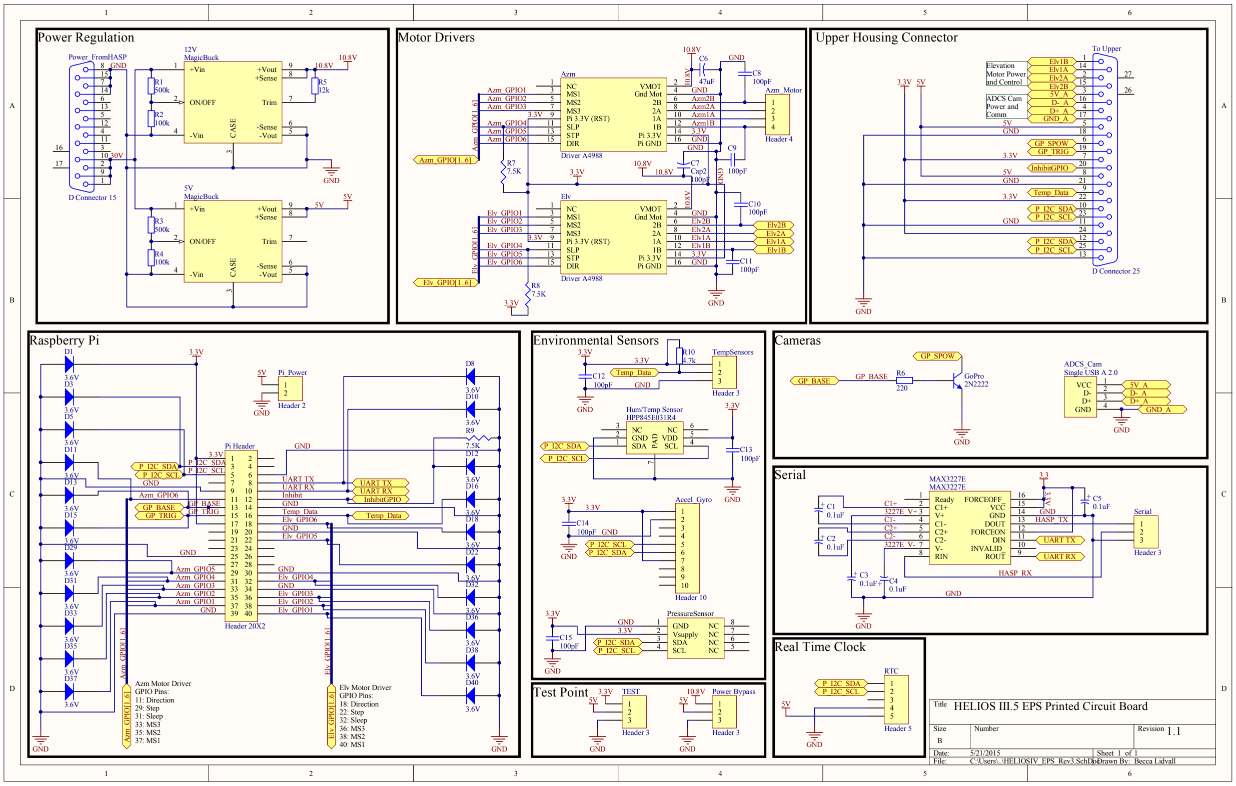

Figure 13: EPS PCP Schematic

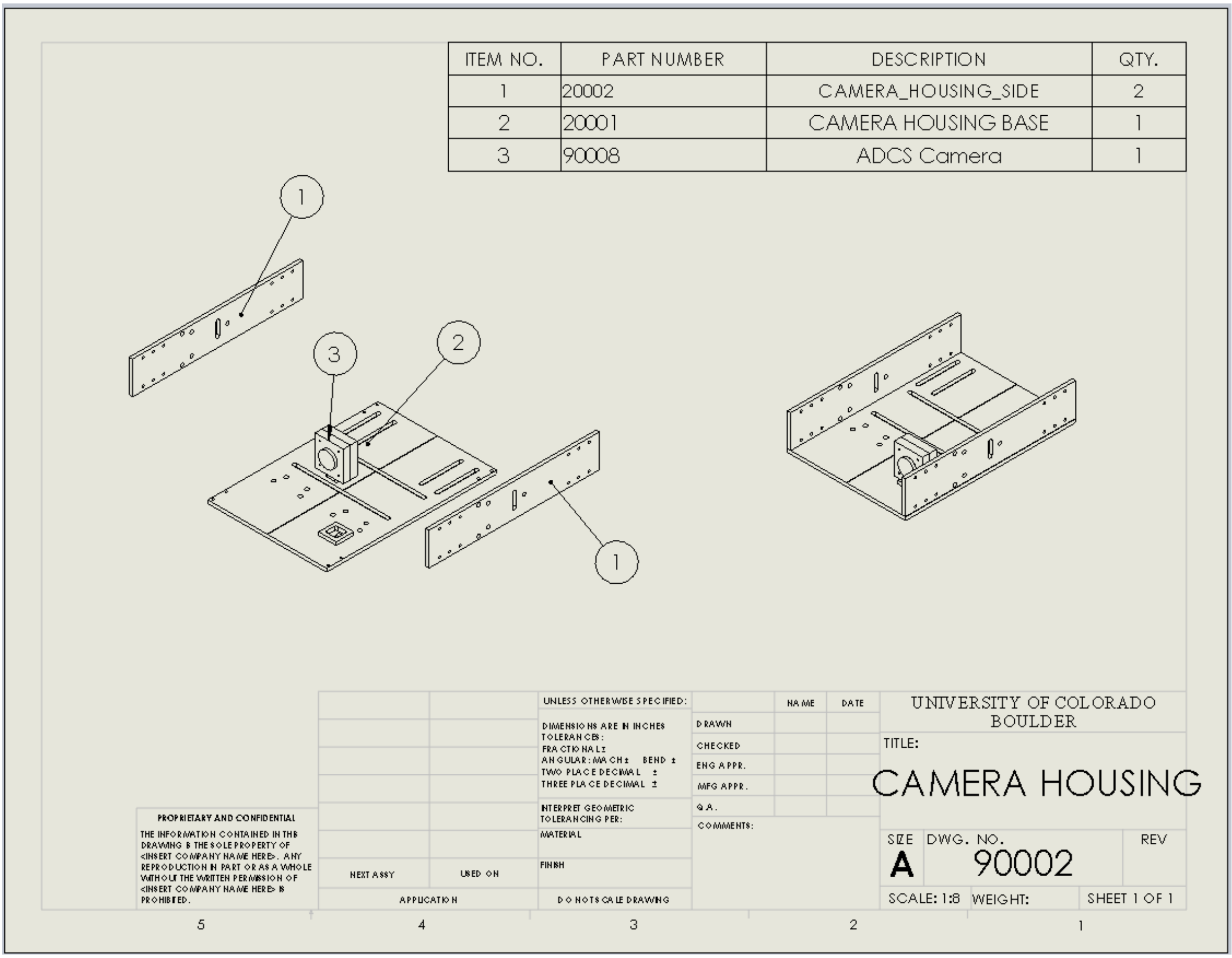

Figure 14: Camera Assembly (units in cm)

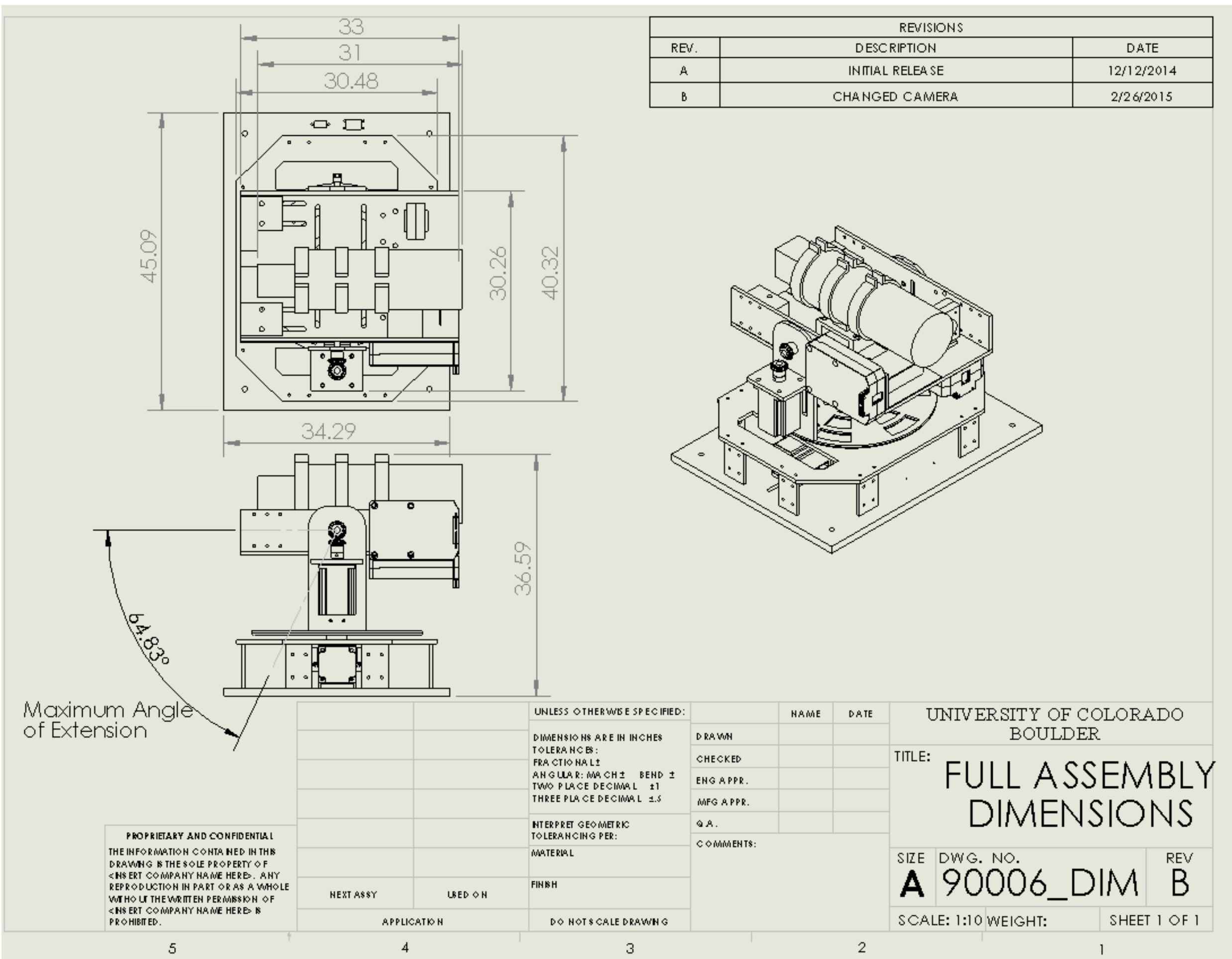

Figure 15: Full Assembly (units in cm)

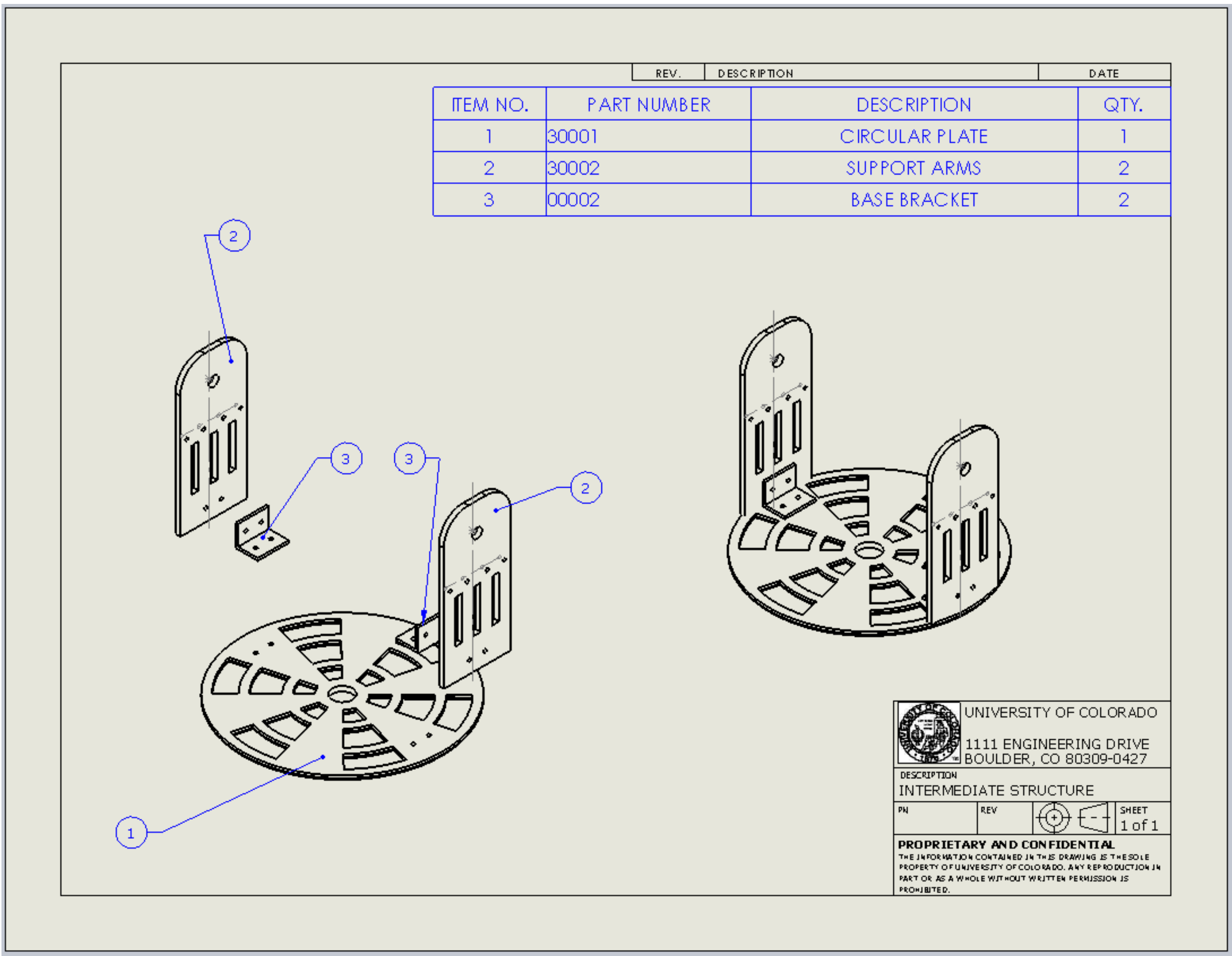

Figure 16: Intermediate Structure (units in cm)

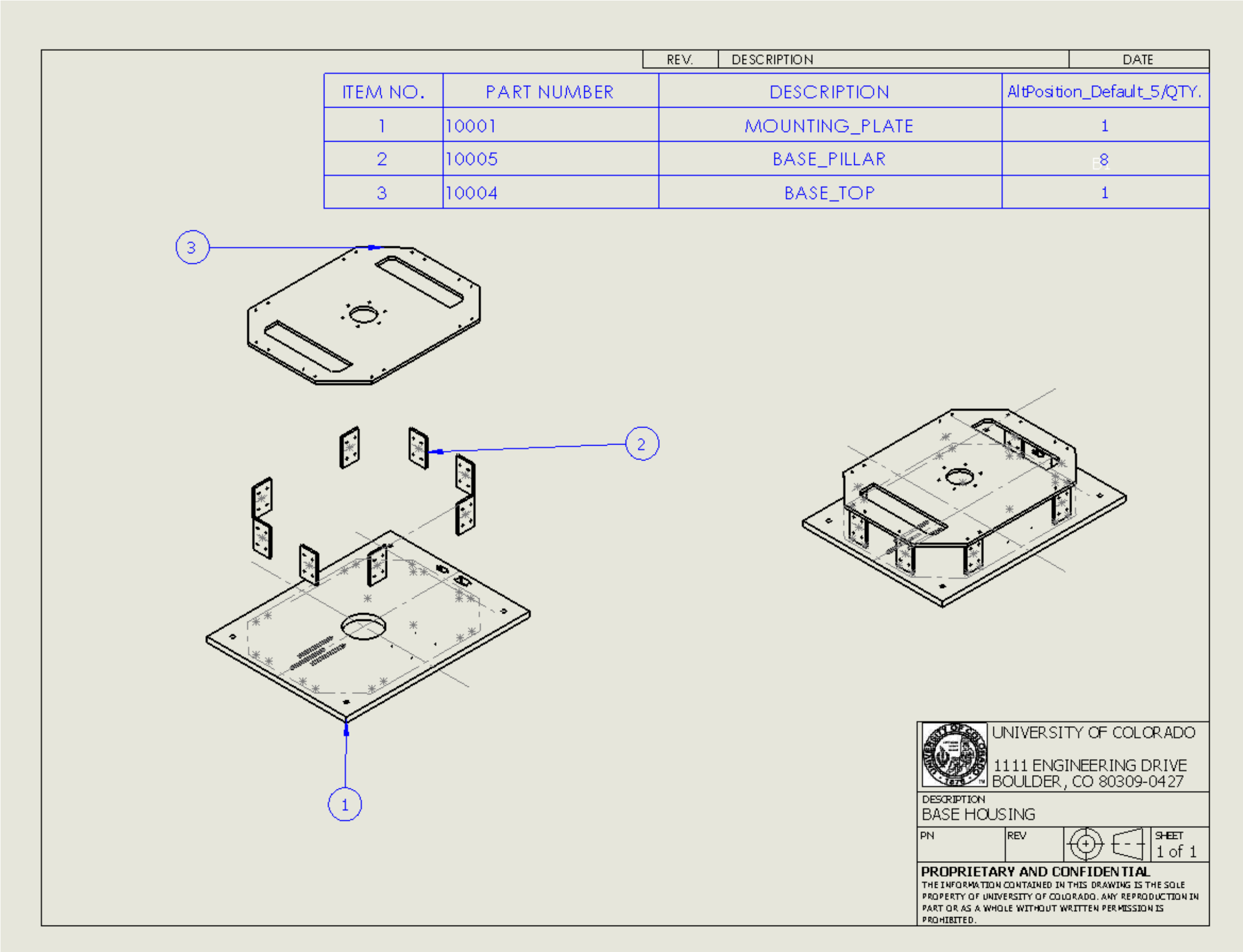

Figure 17: Base Housing (units in cm)

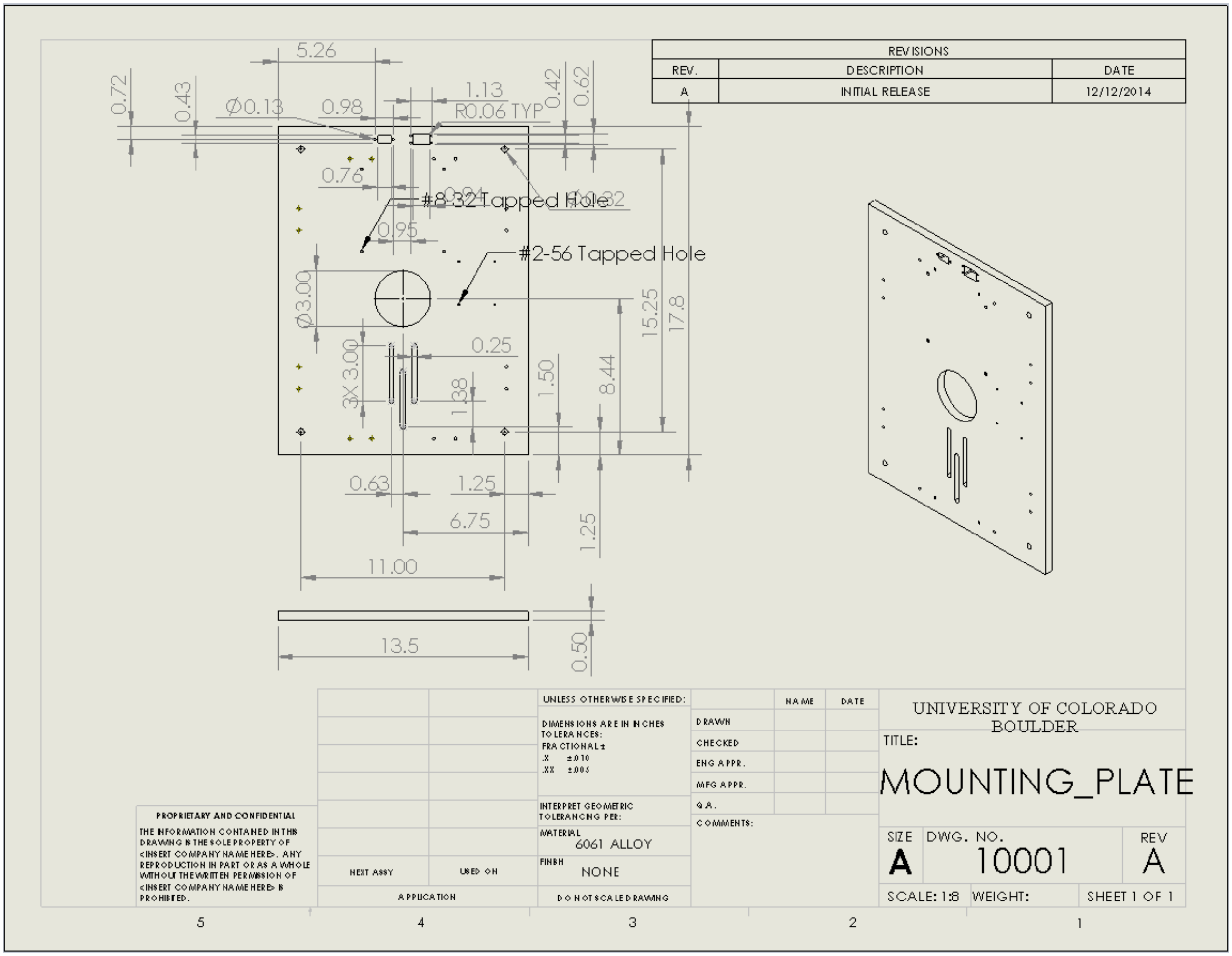

Figure 18: Mounting Plate (units in cm)

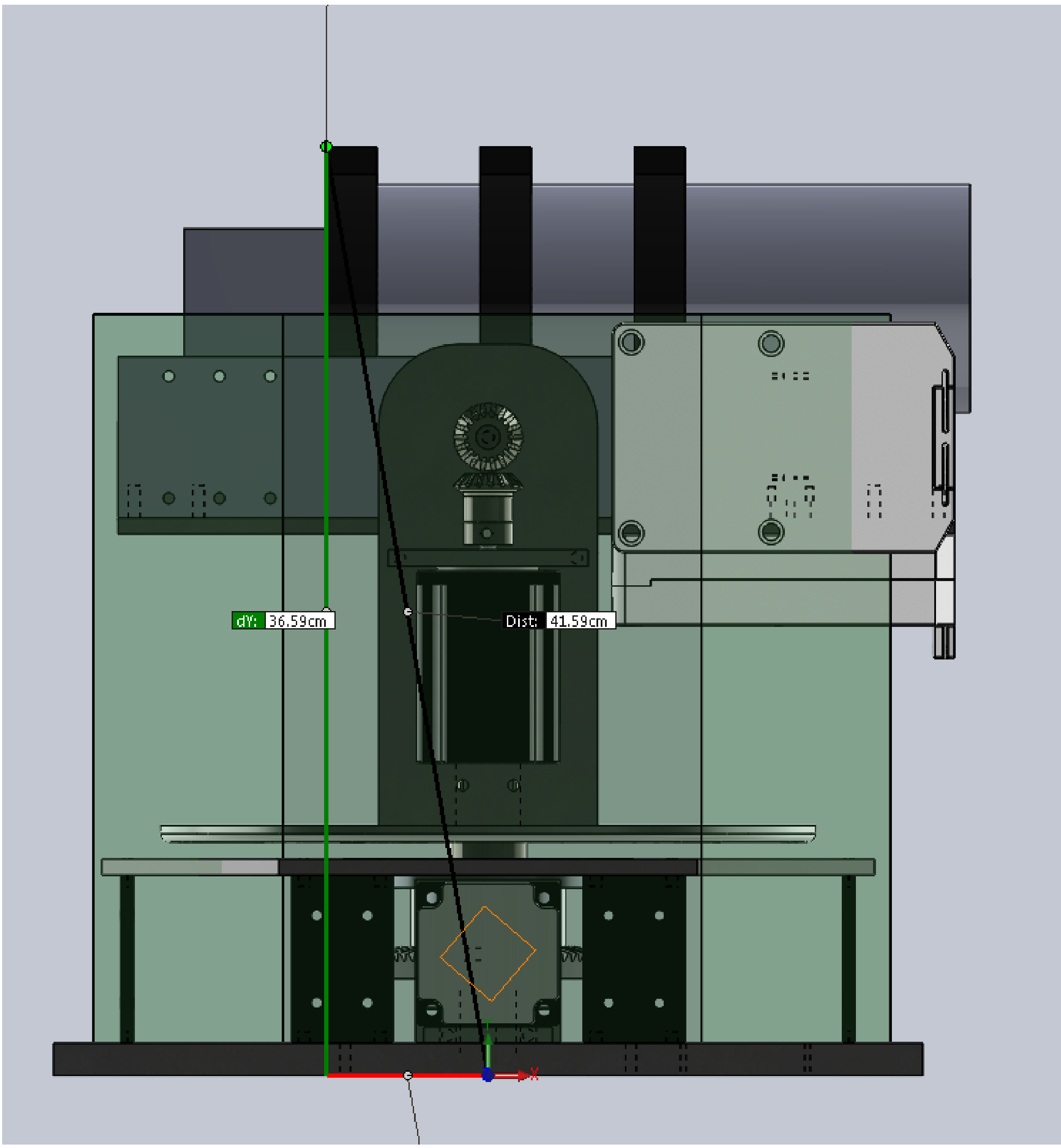

Figure 19: Height at Resting Position (units in cm)

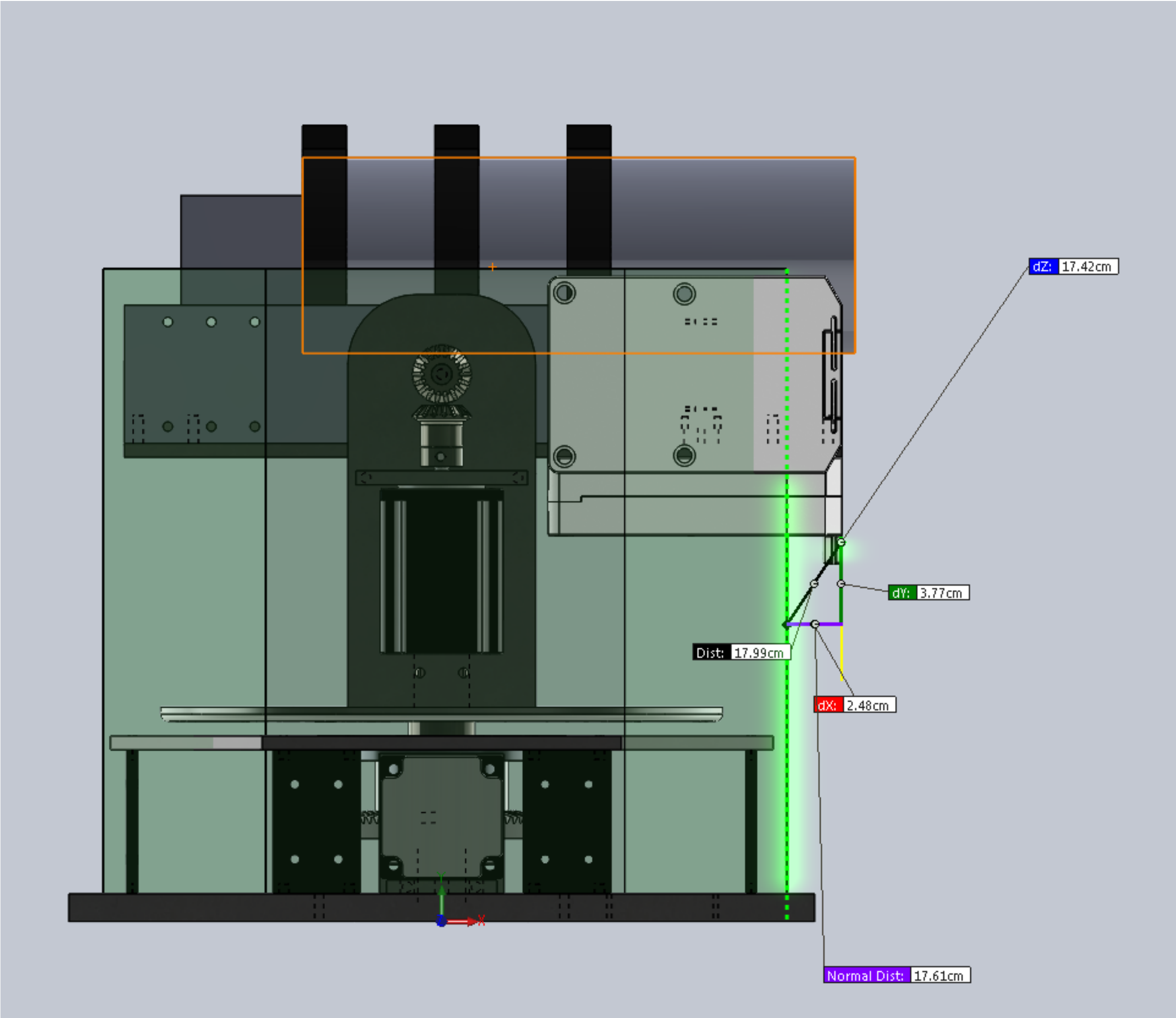

Figure 20: Width at Resting Position (units in cm)

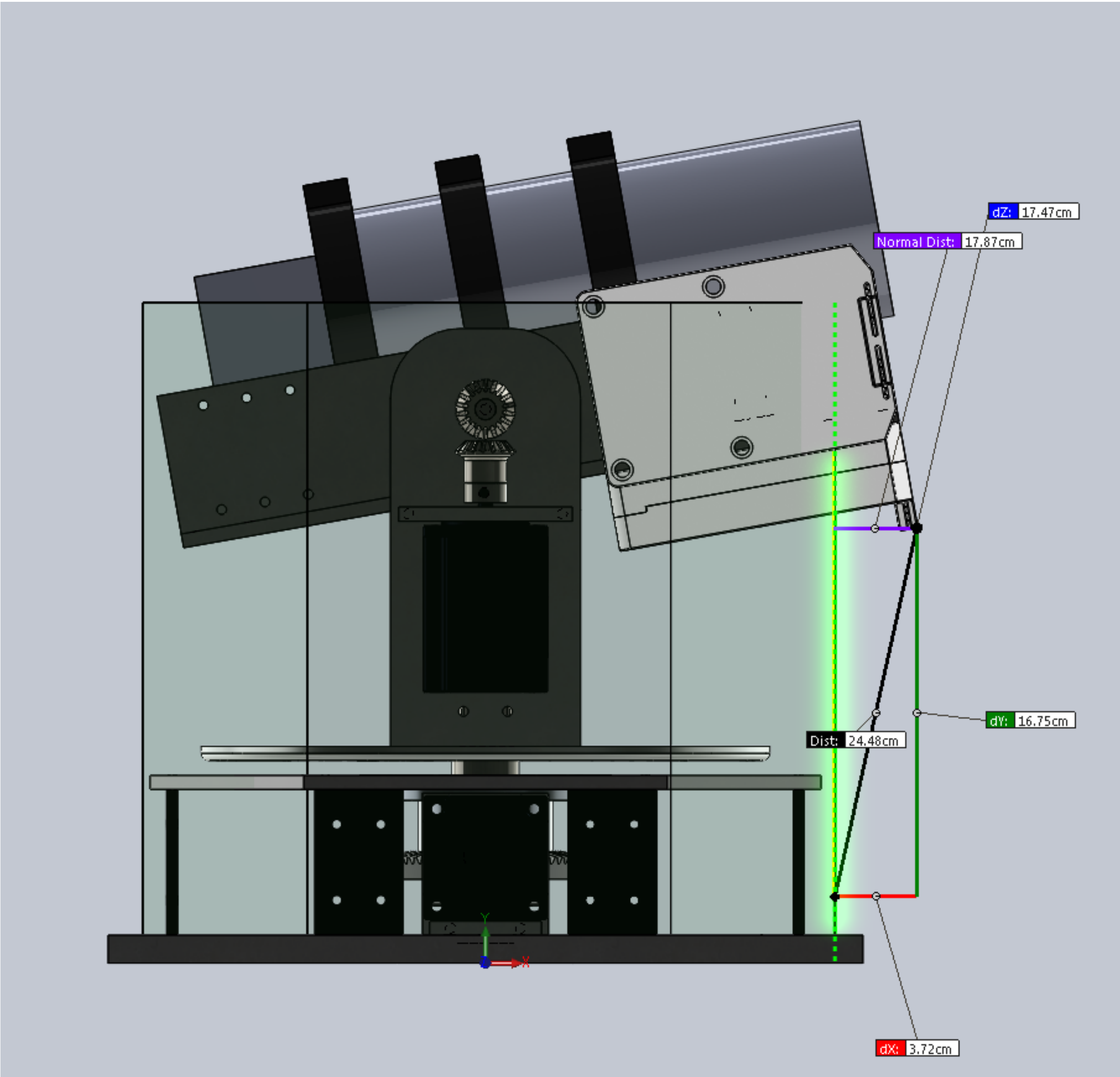

Figure 21: 10° extension width (units in cm)

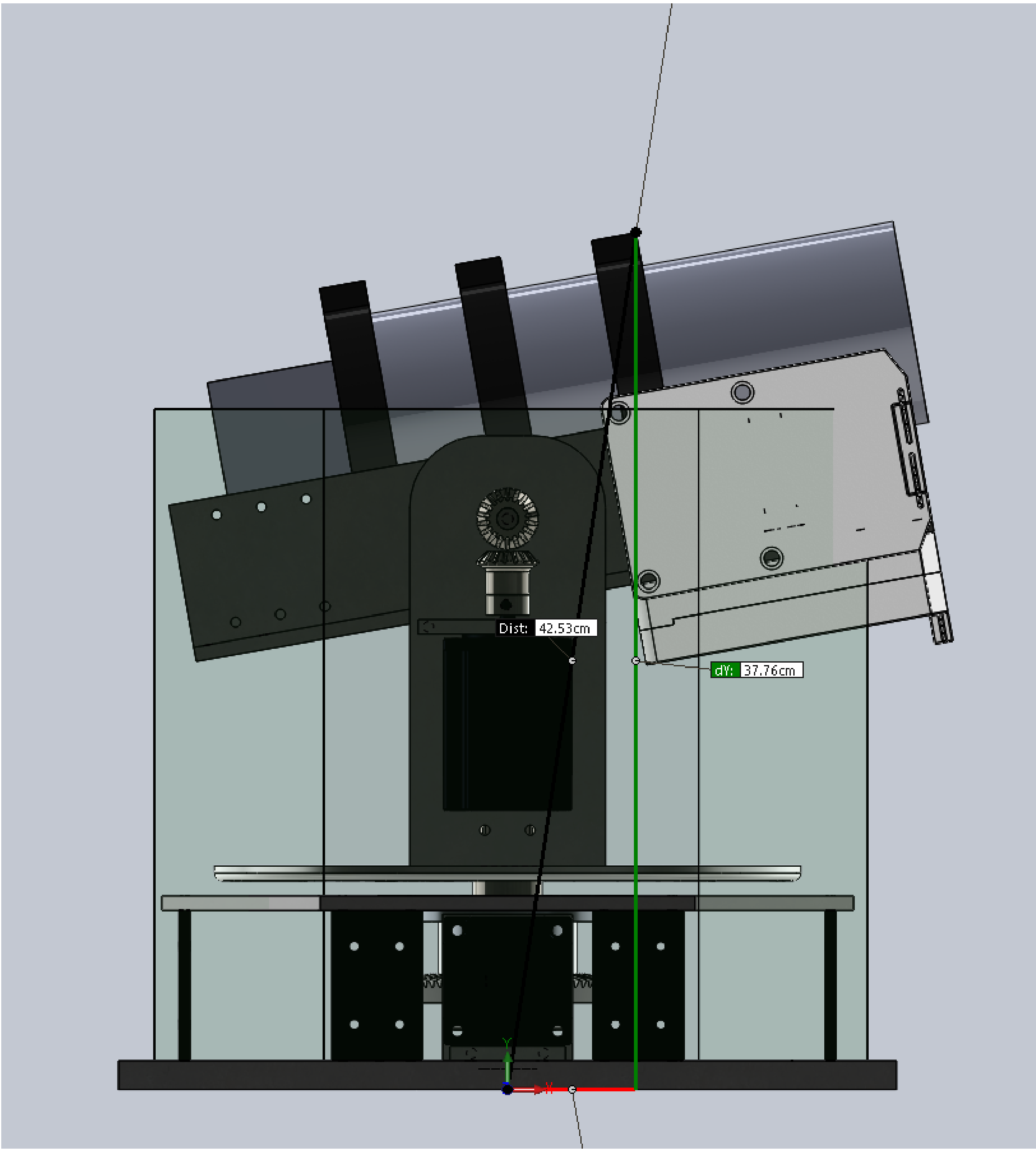

Figure 22: 10° extension height (units in cm)

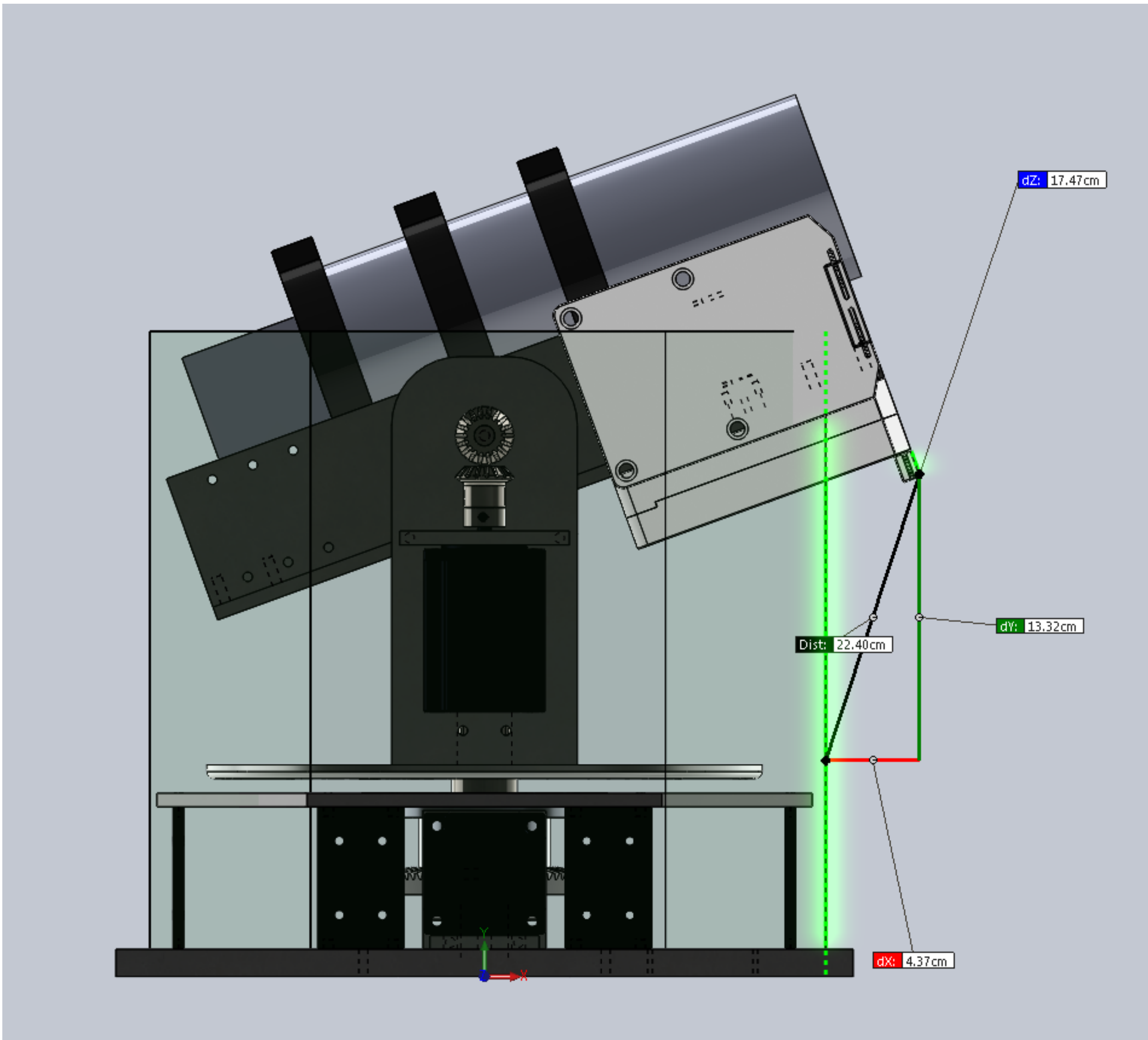

Figure 23: 20° extension width (units in cm)

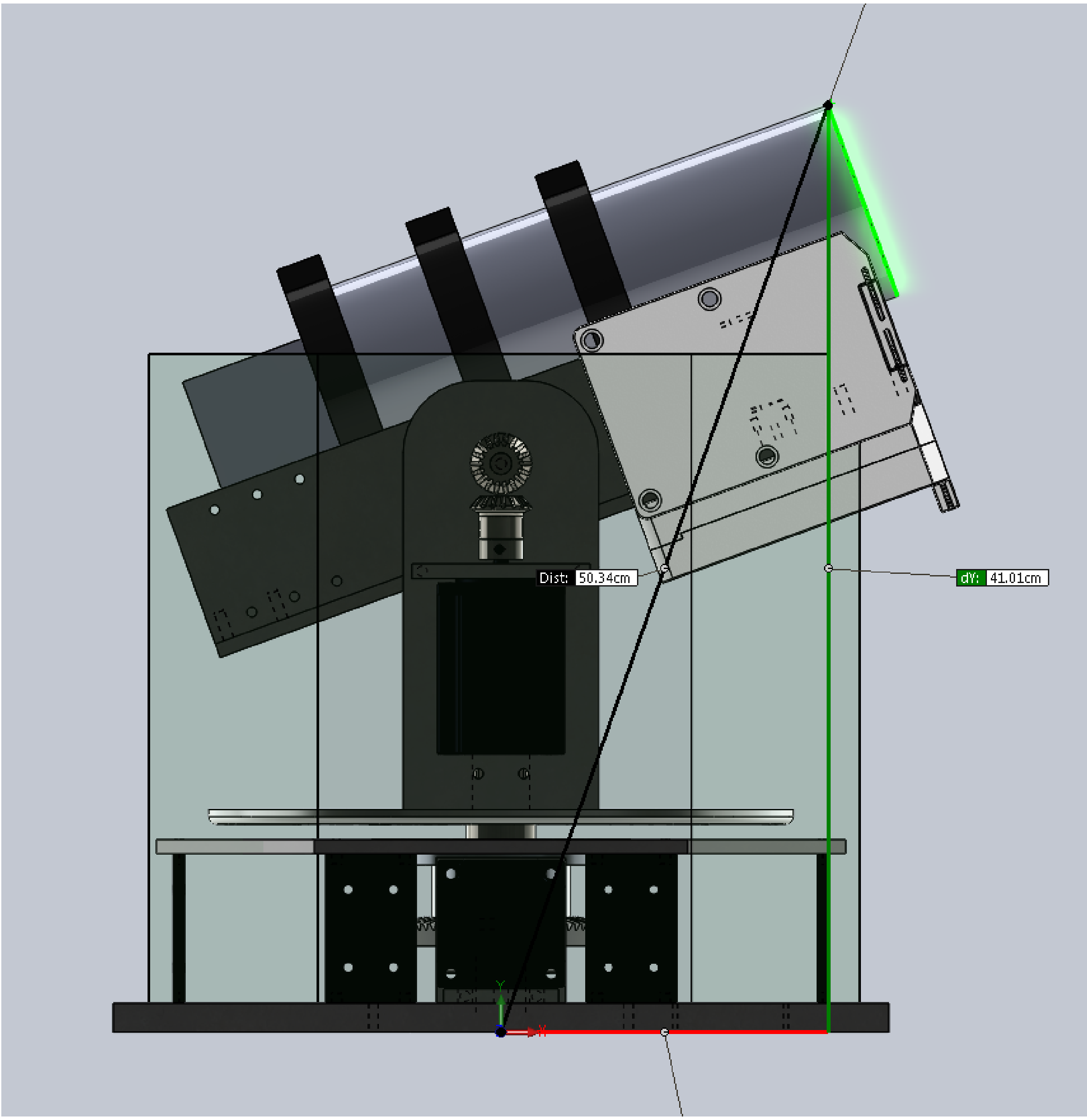

Figure 24: 20° extension height (units in cm)

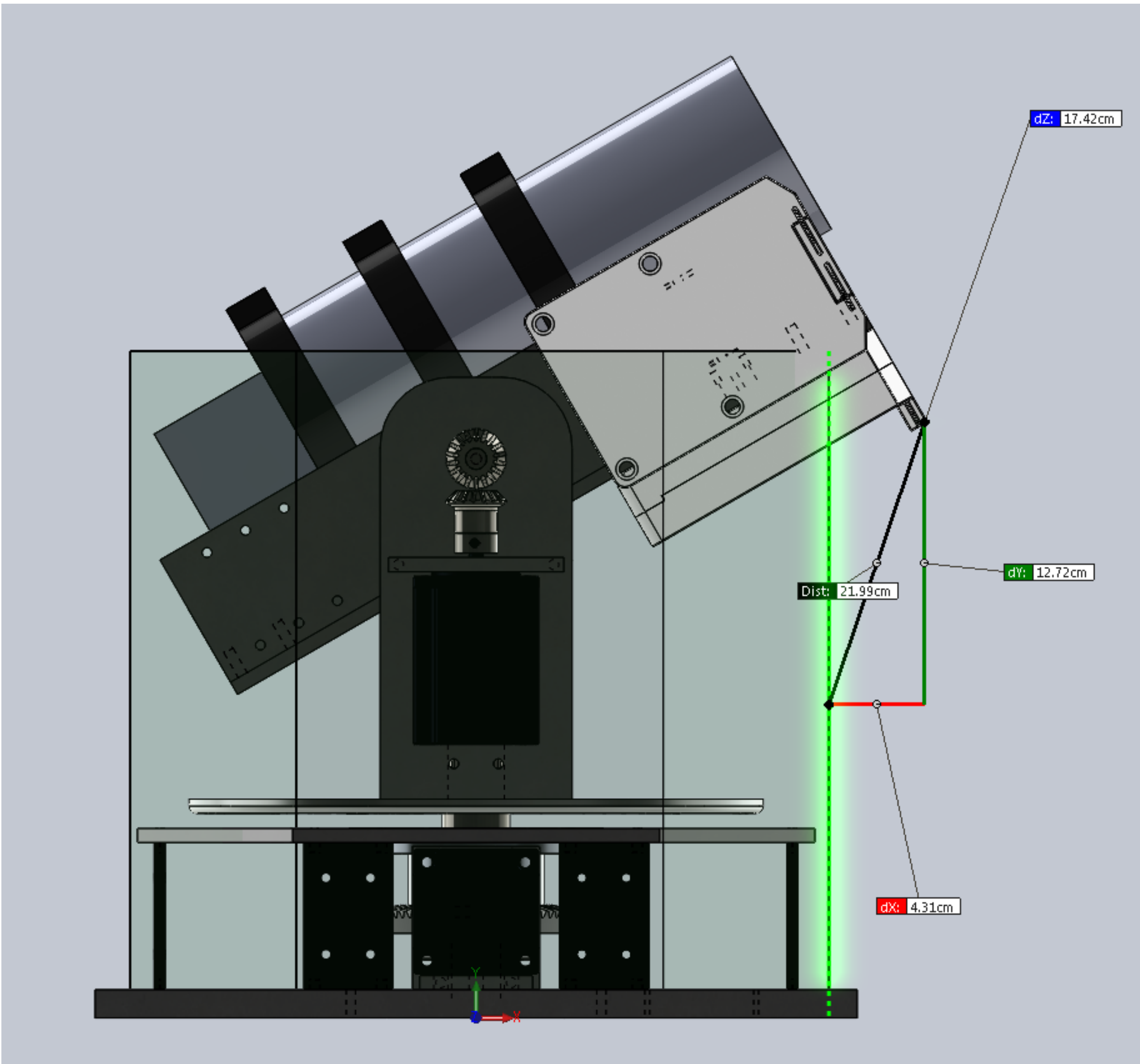

Figure 25: 30° extension width (units in cm)

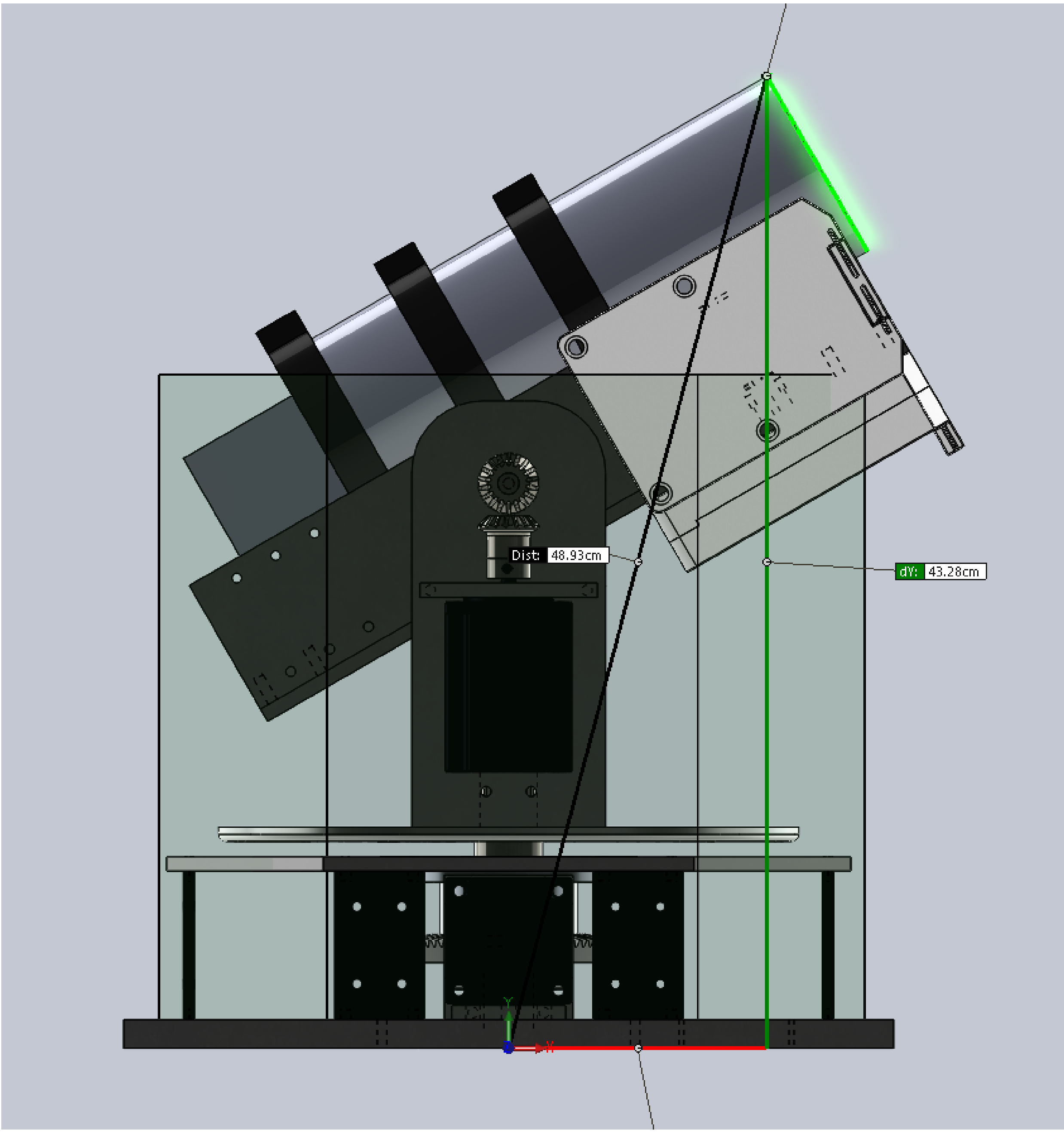

Figure 26: 30° extension height (units in cm)

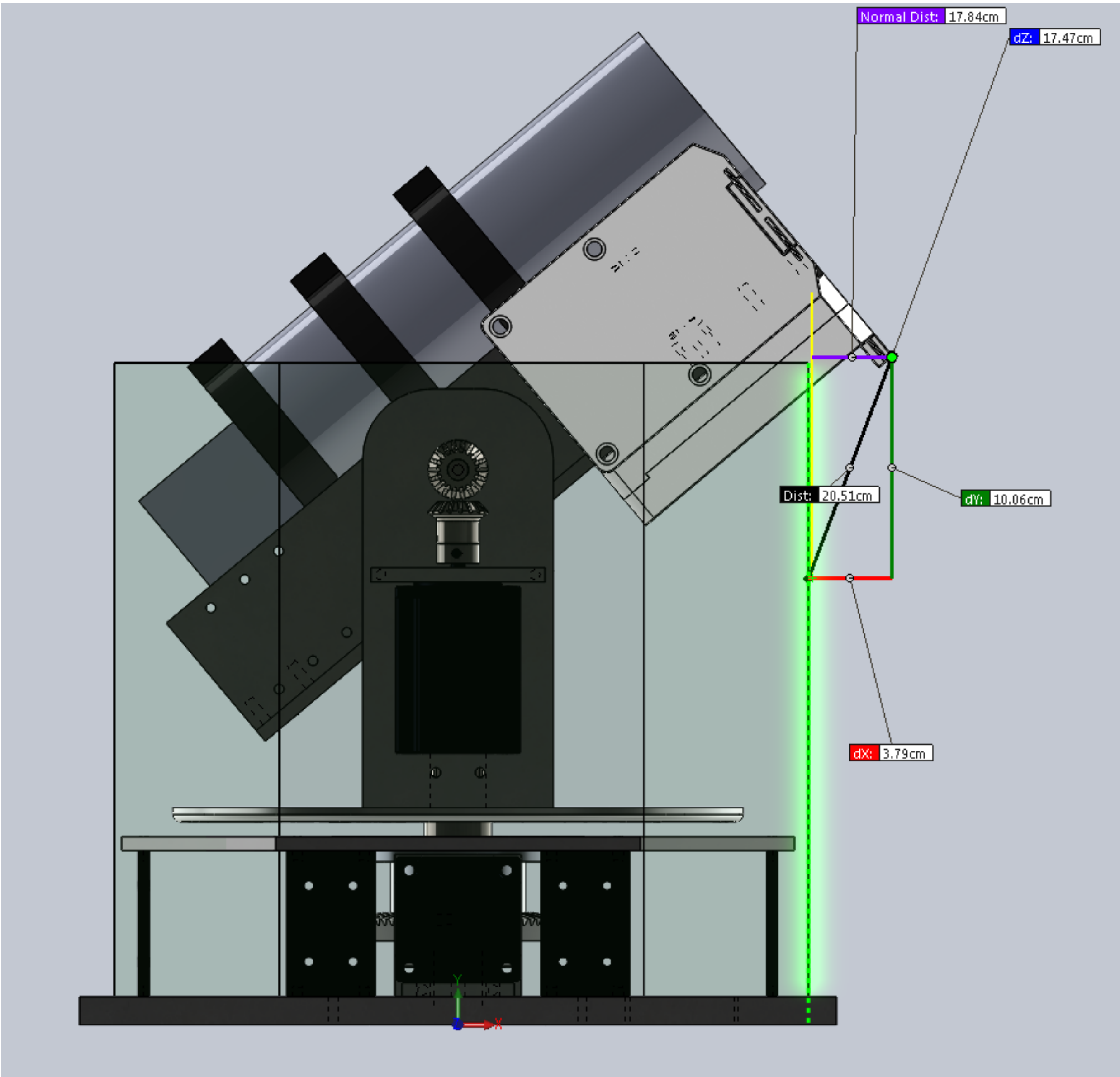

Figure 27: 40° extension width (units in cm)

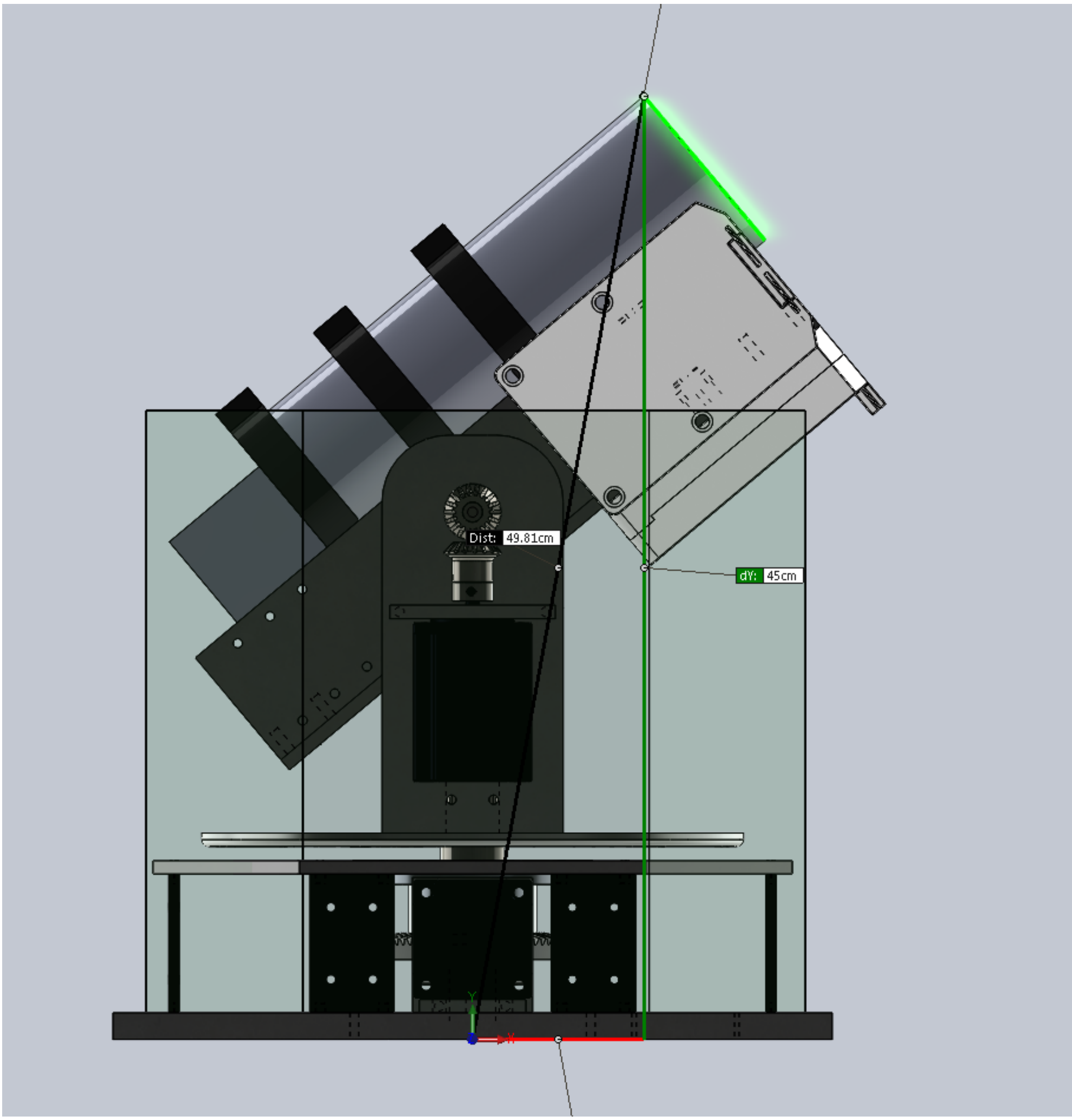

Figure 28: 40° extension height (units in cm)

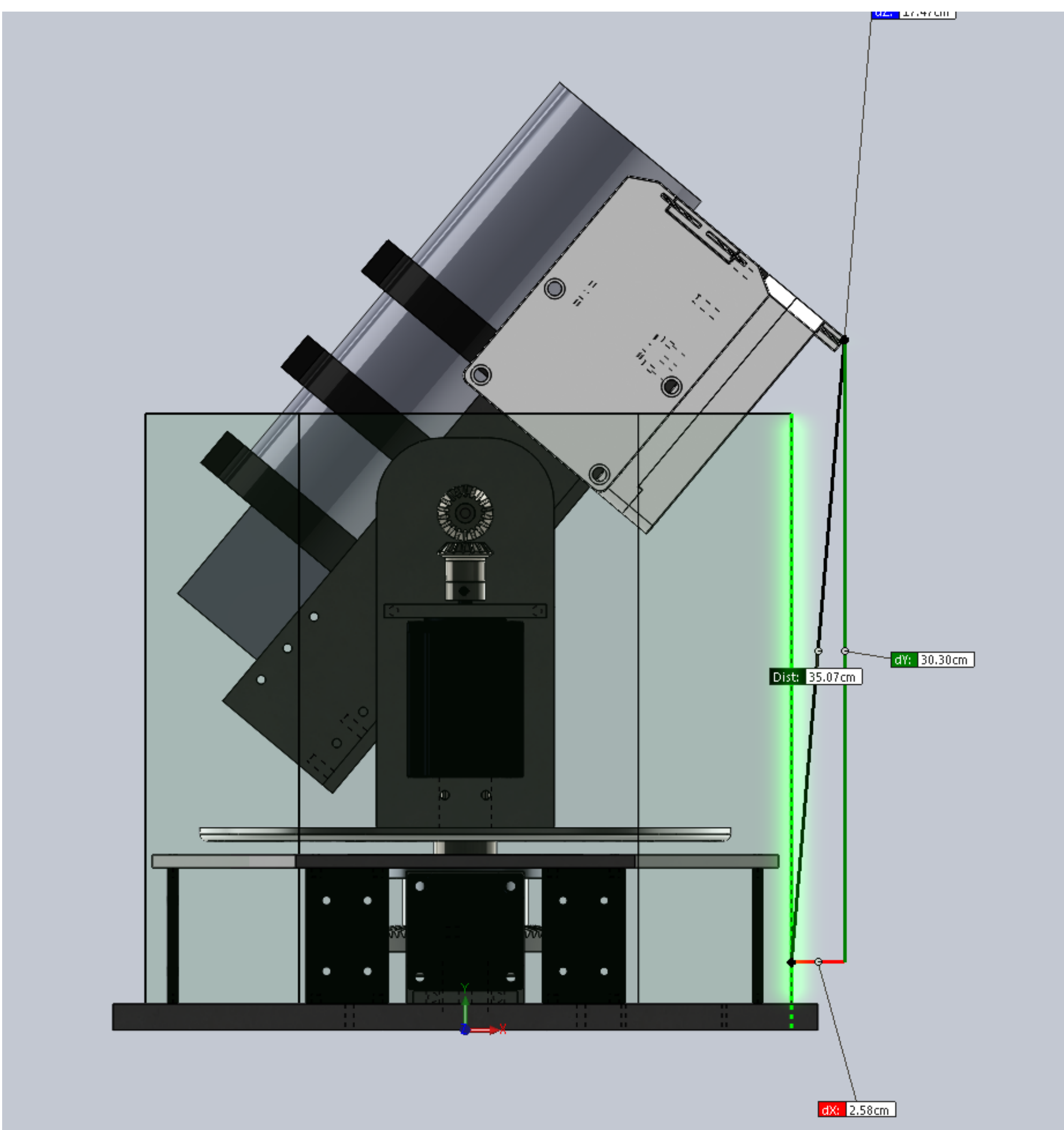

Figure 29: 50° extension width (units in cm)

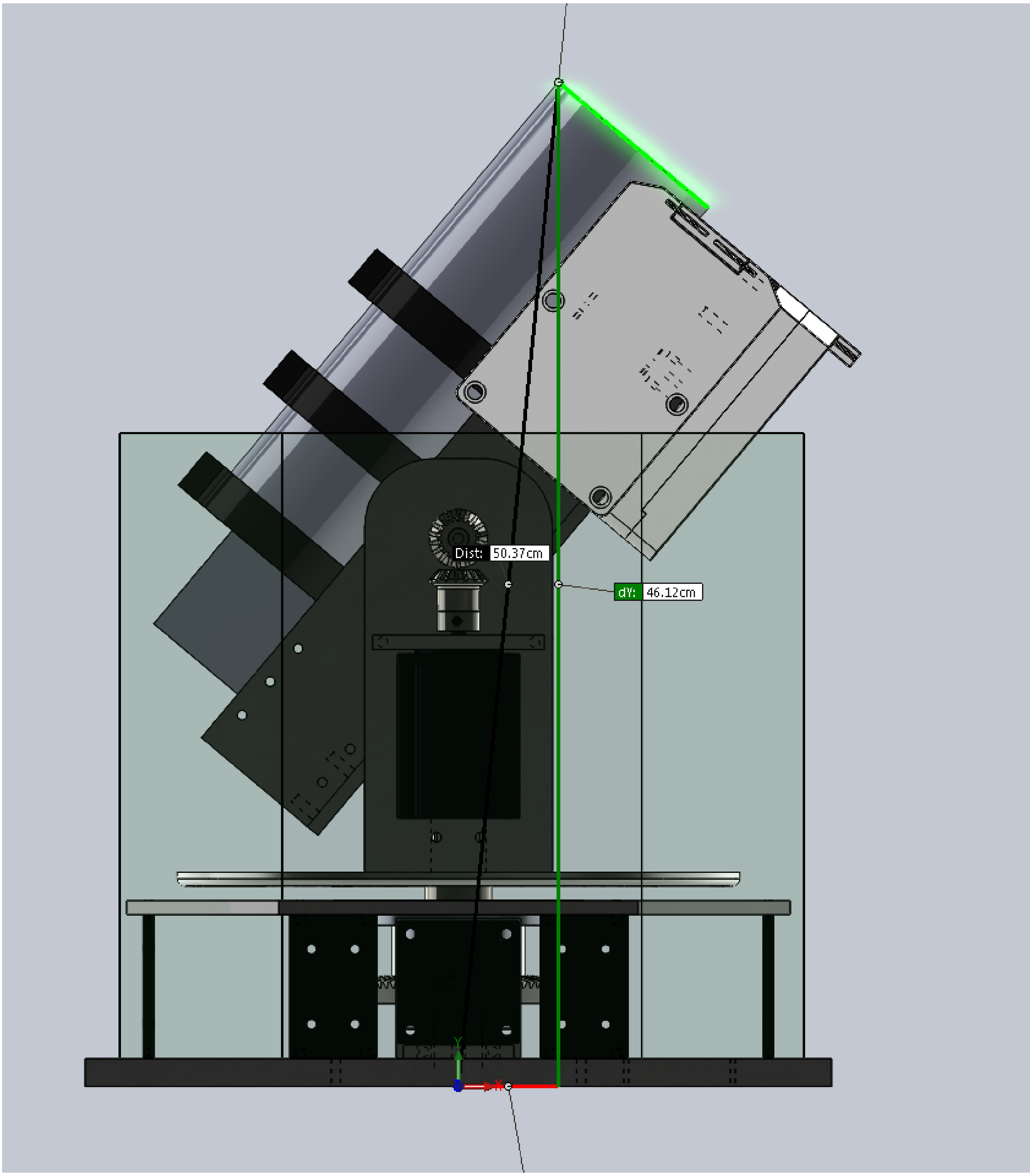

Figure 30: 50° extension height (units in cm)

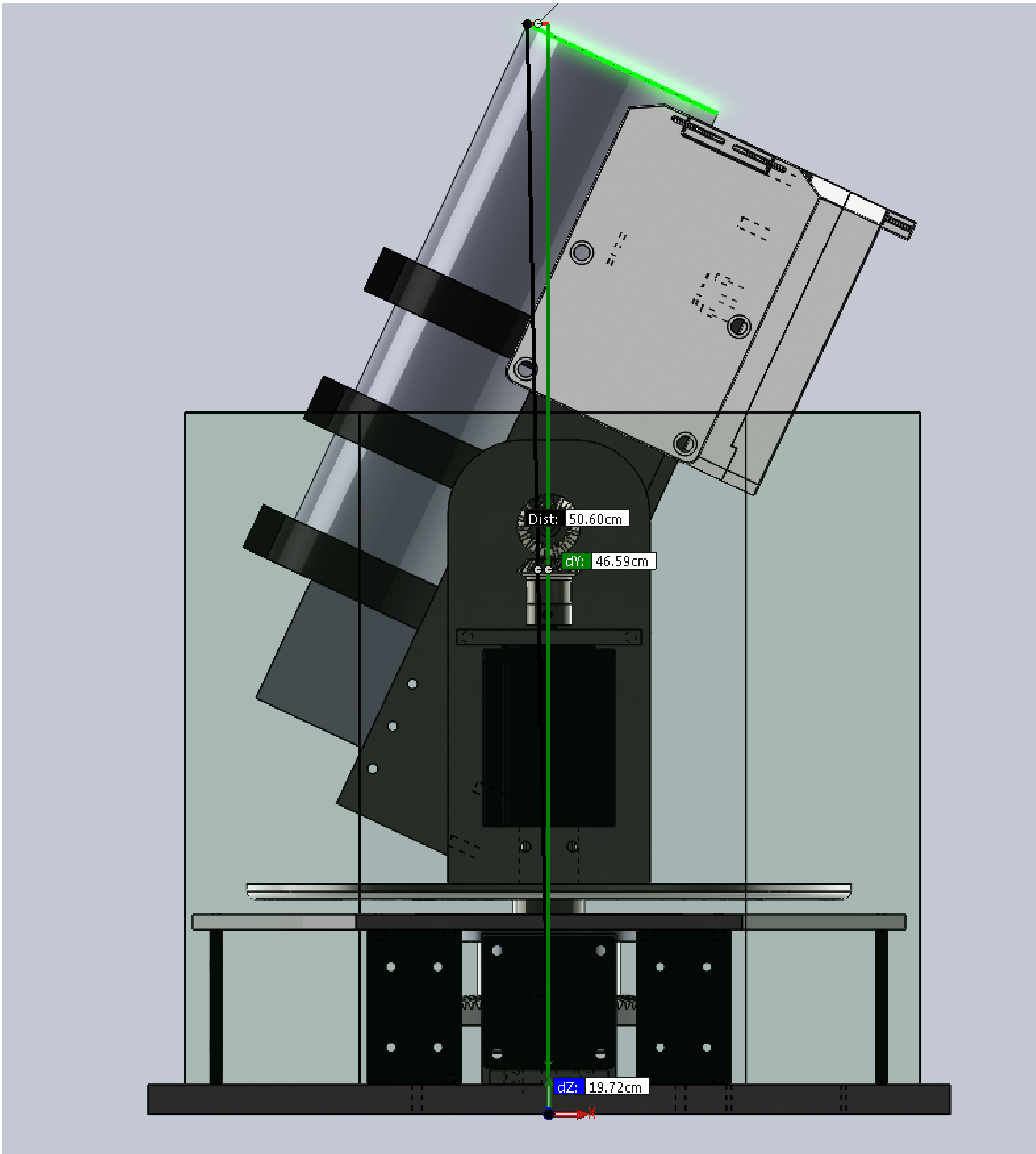

Figure 31: Full extension height (units in cm)

References

1. Paige Arthur, Cooper Benson, Brandon Boiko, Ryan Cutter, Flor Gordivas, Kristen Hanslik, Rebecca Lidvall, Kevin Paynter, Dylan Richards, Alex St. Clair, and Anthony Torres. Hydrogen-Alpha Exploration with Light Intensity Observation Systems IV Proposal. Feb 27, 2015.
2. Paige Arthur, Cooper Benson, Ryan Cutter, Flor Gordivas, Kristen Hanslik, and Dylan Richards. Hydrogen-Alpha Exploration with Light Intensity Observation Systems IV Final Science Report. Dec 11, 2015.