Colorado Space Grant Consortium

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Colorado Space Grant Consortium
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December 18, 2009

Dr. T. Gregory Guzik
Department of Physics & Astronomy
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Baton Rouge, LA 70803-4001

Dear Dr. Guzik,

Thank you for taking the time to read our proposal. As the selection process nears, we look forward hearing from you. The previous University of Colorado at Boulder HASP teams of 2008 (DIEHARD) and 2009 (BOWSER) have received valuable results in determining the feasibility of high altitude balloon-stationed observatories in the visible spectrum. The University of Colorado at Boulder's HASP 2010 team is proposing an exciting opportunity to further pursue the overall feasibility of high altitude platforms, which our research also allows us to work with professional experts such as Dr. Eliot Young. We find the HASP platform the most suitable and beneficial device to test atmospheric disturbances at high altitudes, as well as develop a pointing system specifically for a balloon platform.

Sincerely the HASP 2010 team,

Brian Ibeling
Project Manager

Josh Tiras
Systems Engineering Lead

Amy Boncella
Science Lead

Jackie Myrose
C&DH/Software Lead

Craig Riggins
Power/Electronics Lead

HASP Student Payload Application for 2010:

Payload Title: Selective Pointing Apparatus for Research of Turbulence and Atmospheric Noise Variation

Payload Class: (circle one) Small [✓ Large]	Institution: University of Colorado	Submit Date: 12/18/09

Project Abstract

The University of Colorado – Boulder team will continue to determine the feasibly of high altitude observatories by characterizing the atmospheric disturbances through measurements of the variations in the brightness of a star for the duration of the nighttime flight.

This mission focuses on the specific problem of characterizing atmospheric scintillation and extinction to test the feasibility of observing exoplanets transiting stars from the stratosphere with a signal to noise ratio of 10^5. This will be achieved through the development of a gimbaled pointing telescope, capable of acquiring and maintaining a 0-2 magnitude star within its field of view. A high resolution camera will be mounted to the telescope and capture images at a rapid rate, which will then be compiled and integrated in order to construct a photometric composition of the star. This composition will be analyzed for photometric stability, with respect to brightness and scene of the star. Additionally accelerometer and gyroscope sensors will take recordings regarding the turbulence, directional orientation and stability of the platform.

Team Name: SPARTAN-V	Team or Project Website: http://spacegrant.colorado.edu

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1.0 Mission Overview

1.1. Mission Statement

Team SPARTAN-V (Selective Pointing Apparatus for Research of Turbulence and Atmospheric Noise Variation) is working towards the eventual goal of supporting very precise photometry from balloon-borne telescopes. This mission focuses on the specific problem of characterizing atmospheric scintillation and extinction to test the feasibility of observing exoplanets transiting stars from the stratosphere with a signal to noise ratio of 10^5. To achieve this, SPARTAN-V will sense platform motion in order to point at a bright star and measure that star's photometric output. In addition, SPARTAN-V could potentially serve on a startracker for future payloads.

1.2. Mission Premise

Currently, the two main methods of observing stars are ground based and orbital based devices. The disadvantage of ground based viewing is atmospheric disturbance; this is overcome by devices such as Hubble Space Telescope. The major issue with Hubble is the time and money required to build, launch, and maintain such a device. The definite advantages to balloon observatories are the low cost and the ability to observe above 99.5% of Earth's atmosphere.

The DIEHARD and BOWSER payloads on previous HASP flights have shown that star imagery on a high altitude balloon is possible. The next step is to determine how clear and detailed the images which high altitude balloon payloads are able to obtain at near space. In order to achieve the goals of the SPARTAN-V platform, the payload will examine the variations in brightness of individual stars due to differing atmospheric anomalies in the upper atmosphere.

One anomaly experienced within the stratosphere when viewing a star is the extinction of starlight. As photons from stars enter the atmosphere, there is potential for them to collide with gas atoms or molecules. This causes the atoms to excite, and redirect the light in a random direction, which is known as extinction. This means that potentially less photons from the star arrive at an observation point on the Earth due to their contact with the atmosphere.

Another anomaly experienced within Earth's stratosphere is the scintillation of starlight, which is caused by light being scattered and refracted through small-scale fluctuations in air density. These fluctuations are mainly generated from turbulent mixing of air with different temperatures. Scintillation causes the star's center of brightness to appear to move, thus causing inaccuracies in photometry measurements.

Through focusing on a single 0-2 magnitude star for a minimum of 60 seconds, SPARTAN-V will be able to characterize a star's extinction and scintillation. In order to achieve this science mission, SPARTAN-V will be highly dependent upon an accurate pointing system capable of correlating for HASP rotations, along with the platform's movement across the upper atmosphere. Once these variations are seen, SPARTAN-V will be able to define the extent of the atmosphere's distortion upon the HASP platform.

1.3. Mission Background

The following sections show previous experiments regarding the feasibility of high altitude observatories.

1.4. Photometry

There is currently widespread interest in the discovery and research of exoplanets in the far reaches of space. One way of detecting an exoplanet is by searching for periodic transits. A transit of an exoplanet is when it passes between the star it is orbiting and the observer's view. As the planet travels in front of the star, some of the light from the star is blocked and observed by the diminished brightness of the star. In order to detect exoplanets, researchers can focus a telescope on a star for a long period of time and observe how the star's brightness varies with time. If there are periodic dips observed in the brightness, it can be deduced that there is a satellite orbiting the star which is causing a shift in the light.

NASA's Kepler Mission is designed to detect habitable planets using this method. The spacecraft was launched into orbit around the sun and will look out into the Milky Way to detect transits of exoplanets. Kepler will stare out at the same stars for three and a half years in order to try to detect transit behaviors in star systems. Transits are detected in planets in systems with poles that are nearly perpendicular to an observer's line of sight.

The SPARTAN-V payload will need to develop a pointing telescope to keep a star within its field of view. SPARTAN-V will not likely be able to detect any extrasolar planets, but it will hopefully give an indication of the photometric capabilities of these high altitude balloons. It will also hopefully characterize the turbulence of the atmosphere at an altitude that is above 99.5% of Earth's atmosphere. In order to collect the data necessary to meet the science goal, the payload must be a very accurate pointing system. This will be a lofty task to complete, but it should not be impossible. One single star must be kept in the field of view for the entire flight. If this can be accomplished, then the pointing system can be used in future missions that can further the science goals of the mission.

1.5. Mission Requirements

Type	Goal	Mission Science Goal
G	G	Team SPARTAN-V is working towards the eventual goal of supporting very precise photometry from balloon-borne telescopes. This mission focuses on the specific problem of characterizing atmospheric scintillation and extinction in order to support the feasibility of observing exoplanets transits stars from the stratosphere with a signal to noise ratio of 10^5. To achieve this, SPARTAN-V will sense platform stability in order to point at a bright star measure that star's photometric output. In this way, SPARTAN-V will create a telescopic pointing system capable of astronomical observing for future payloads.

Type	Objective	Mission Objective Level 0	Reference
O	O1	SPARTAN-V will observe the photometric stability of a zeroth magnitude star from the stratosphere with the ability to sense photometric flux to 10^5 resolution	G
O	O2	SPARTAN-V will characterize the scintillation on zeroth magnitude stars from the stratosphere	G
O	O3	SPARTAN-V will be able to observe and maintain a star within its field of view.	G
O	O4	SPARTAN-V will measure the amplitude and frequency of pointing errors in the typical balloon environment.	G
HC	O5	SPARTAN-V will comply with all requirements set by HASP.	G

Type	Requirement	O1 Objective Requirements Level 1	Reference
F	R1.1	SPATAN-V shall collect 10^5 photons per pixel	O1, O2 CR: R3.2
P	R1.2	SPARTAN-V shall collect 1000 frames per star	O1, O2
P	R1.3	SPARTAN-V shall defocus a star to cover 100 pixels	O1, O2
F	R1.4	SPARTAN-V shall have a focal length 400-600 mm	O1, O2
P	R1.5	SPARTAN-V shall have a light sensing device capable of capturing 10 million photons per sample	O1, O2

Type	Requirement	O2 Objective Requirements Level 1	Reference
F	R2.1	SPARTAN-V shall identify the centroid/s of a star.	O2
F	R2.2	SPARTAN-V shall characterize the shape of a star.	O2

Type	Requirement	O3 Objective Requirements Level 1	Reference
F	R3.1	SPARTAN-V shall be able to locate a zeroth magnitude star.	O3

F	R3.2	SPARTAN-V shall maintain a star within its field of view for 60 seconds	O3, CR: R1.1

Type	Requirement	O4 Objective Requirements Level 1	Reference
P	R4.1	SPARTAN-V shall determine the pitch rate, roll rate, and yaw rate at 50 Hz	O4
P	R4.2	SPARTAN-V shall determine the pitch rate, roll rate, and yaw rate to one-hundredth of a degree per second	O4
P	R4.3	SPARTAN-V shall determine X,Y, and Z accelerations at 1000 Hz	O4
P	R4.4	SPARTAN-V shall determine X,Y, and Z accelerations to one-hundredth of a G-force	O4

Type	Requirement	O5 Objective Requirements Level 1	Reference
HC	R5.1	The payload shall weigh no more than 20 kg.	O5
HC	R5.1	The payload shall be no bigger than 38 cm x 30 cm x 30 cm.	O5
HC	R5.1	The payload shall allow for secure mounting to the HASP frame, remaining intact up to 10 g vertical and 5 g horizontal shock.	O5
HC	R5.1	The payload shall have a twenty pin EDAC 516 interface to the HASP system power and analog down-link channels.	O5
HC	R5.1	The payload shall draw no more than +30 VDC or 2.5 amps and shall convert the provided +30 VDC to the necessary voltages required inside the BOWSER payload.	O5
HC	R5.1	The payload shall allow for three discreet command functions from HASP payload using EDAC 516-020 interface. One shall be for powering the payload on. One shall be for powering the payload off.	O5
HC	R5.1	The payload shall use a DB9 connector, RS232 protocol, with pins 2, 3, and 5 connected.	O5
HC	R5.1	The payload shall allow for a serial down-link functioning at 4800 baud.	O5
HC	R5.1	The payload shall transmit data packages that show the payload’s health status using unique header identification.	O5

Type	Requirement	O1 Objective Requirements Level 2	Reference
F	R1.1.1	SPARTAN-V shall integrate photons from a single star for 60 seconds	R1.1, R1.2, R1.3
P	R1.1.2	SPARTAN-V shall capture 10^10 photons over a given integration period	R1.1, R1.2, R1.3

P	R1.1.3	SPARTAN-V shall collect 1.8 x 10^6 photon/second/pixel	R1.1, R1.2, R1.3

Type	Requirement	O2 System Requirements Level 2	Reference
F	R2.1.1	SPARTAN-V shall be able to image a zeroth magnitude star	R2.1
F	R2.1.2	SPARTAN-V shall be able to analyze pixel values of an image	R2.1
F	R2.2.1	SPARTAN-V shall obtain a focused image of a zeroth magnitude star	R2.2 CR: R1.1.2

Type	Requirement	O3 System Requirement Level 2	Reference
F	R3.1.1	SPARTAN-V shall be able to point to a specified location with an accuracy of three arc-minutes	R3.1
P	R3.2.1	SPARTAN-V shall have a pointing resolution of 10-25 arc-seconds	R3.2
P	R3.2.2	SPARTAN-V shall be capable of analyzing images at a speed greater than 18 Hz	R3.2 CR: R1.3

2.0 Payload Design

2.1. Pointing System

The pointing system is an essential aspect of the SPARTAN-V mission. Therefore research into prior examples of balloon-borne pointing systems is an integral part of the SPARTAN-V design process. A 2006 paper entitled “Demonstration of a Balloon Borne Arc-second Pointer Design” written by Keith D. DeWeese and Philip R. Ward suggested that it is possible to have a high-altitude balloon based pointing system that has the capability of using a telescope to view a celestial target with sub-arcsecond stability. The system proposed uses an azimuth pointing system to coarsely control the azimuth of the structure. On the azimuth system is mounted a pair of pitch and yaw gimbals for the fine pointing of the telescope. This paper gives insight to the solutions found for the many problems in designing accurate and precise optical pointing systems.

The paper detailed a performance test of the system. The system was hung from a bridge crane that swung the system at an amplitude of +/-1 degrees for the jitter tests, and at roughly 15 degrees for the disturbance tests. Analysis of the test results showed that the system demonstrated sub-arcsecond pointing. The paper concluded that a balloon borne instrument pointing at an inertial target is capable of sub-arcsecond pointing stability.

The conclusiveness of these tests demonstrates the feasibility of a balloon-borne pointing system, such as one SPARTAN-V intends to design and construct, and will serve as a model which shall assist in the design process ahead.

2.2. Principle Operation of Experiment

The SPARTAN-V payload shall be running three experiments – pointing, photometric and platform stability. The SPARTAN-V team has identified the development of the pointing system as the critical path of the mission, as the success of the photometric and platform stability are heavily dependent on that of the pointing system in many ways. The science missions will still be pursued as important, but will be secondary objectives in the payload design. The science mission of the SPARTAN-V payload requires that all data being taken is done so during the night phase of the flight. For this reason, it shall be vitally important that the payload may be activated after sunset during flight. Once activated, the entire system shall only have one flight state, which is the continuous process of tracking and maintaining a given star, storing the image data simultaneous to this process.

As stated, the primary experiment shall be comprised of building and developing a selective pointing system with the capacity to track individual stars. The pointing system itself shall be partitioned into two subsections, mechanical and software. The mechanical system shall implement an optical gimbal mount carrying a light sensing device, most likely a CCD camera. The gimbal shall be positioned on the top of the payload to allow for a 360° Azimuth viewing range, and as such the gimbal device shall be capable of rotating at this range. The software subsection of the pointing system shall be developed by the SPARTAN-V team to allow for the finding, tracking and maintaining of a given star. The entire process must be autonomous, and as such the star found shall be purely relative to the orientation of the pointing system and thus shall not be pre-determined. The software system shall be capable of transmitting images from the light sensing device to the computer, where they shall be analyzed and the necessary adjustments to the gimbal orientation made and issued as commands to the mechanical control system. This shall be accomplished empirically by evaluating each image taken and comparing it against a given central boundary range within the image. Once the star breaches that given boundary, a command will be sent to the gimbal motor control to adjust accordingly. This process shall be accomplished accurately and quickly enough such that the star will not be lost to either time intervals or gimbal inaccuracies. The tracking system shall be run continuously, and the pictures taken shall be stored in memory. They can be stored in a compressed form, should the need arise.

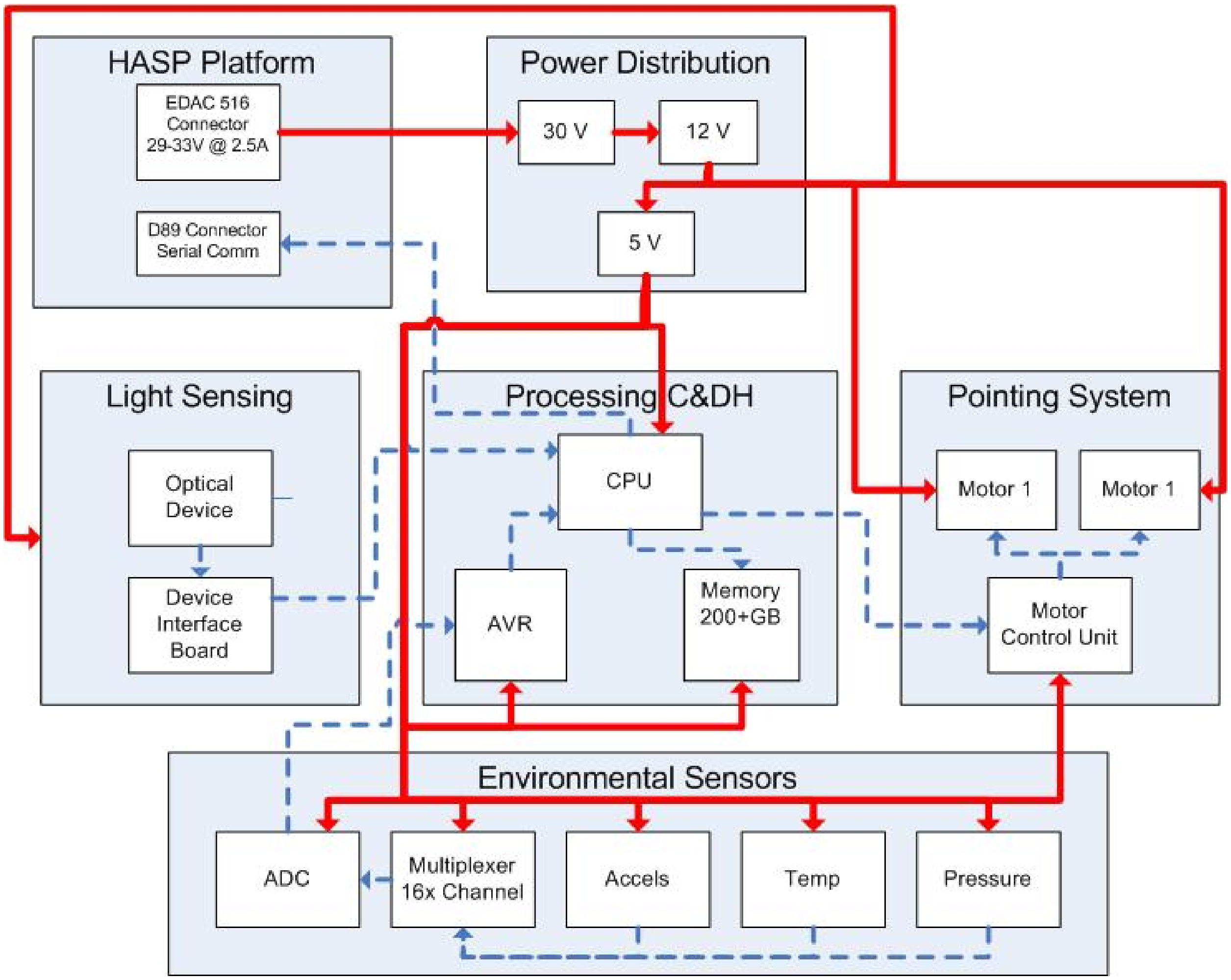


Figure 1: System Block Diagram, showing power flow in red, and data flow in blue.

The photometric system will incorporate an optical sensing device mounted upon the gimbal pointing system. This optical device shall image at a rate specified by the SPARTAN-V requirements, and the images shall be stored to memory. These images will be analyzed post-flight, which SPARTAN-V will require a minimum focal length of 400-600 nm to acquire this.

The platform stability system shall support the function of the pointing system, by providing the feedback necessary to control the pointing system accurately. The system shall consist of a high frequency accelerometer, gyroscopes and the analysis of pixel movement retrieved from the pointing system images. The latter process shall involve recording the pixel offset at every frame taken in order to quantify the movement of the camera relative to a fixed point, the star. In this way, SPARTAN-V shall be capable of characterizing movements within the platform to an accuracy of a pixel, which may be indicative of a given arc-seconds of degree depending on the field of view of the camera. If there is no star in the field of view, the control feedback will be derived from the gyroscope data. The second aspect of the platform stability shall implement accelerometers in order to record acceleration of the payload in the x, y and z axes. High frequency accelerometers shall be mounted to the payload and take measurements of minute accelerations with the intention of characterizing the vibrations within the HASP structure itself. Furthermore, with the correlation between the pixel movement characterization and the high frequency accelerometer data, it will be possible to relate the gravitational forces upon the payload and the resultant change in degree of the field of view.

During the flight, it shall be necessary to send down health and status updates in order to determine the condition of the SPARTAN-V payload and to insure its proper working order. These packets shall contain diagnostic data from the CPU itself, external and internal temperature readings, pressure readings to determine altitude, as well as image files to insure the optical system agrees with the gimbal feedback control. The image data will most likely be compressed to save space and decrease analysis time. The compression code will most likely be hand-made by the SPARTAN-V team, and shall convert the image to black and white and reduce the image size by a given magnitude. In this way, the data shall be made to serve a purpose of simply identifying that the pointing system is indeed oriented and maintaining a star.

SPARTAN-V will utilize the HASP platform’s capability to send commands up to the payload itself. At this point, the only commanding envisioned will be used to correct the pointing system should it become oriented inappropriately and require re-orientation. These commands shall be one-line initiations of the FIND state of the pointing system, where the pointing system shall begin to search for a new star to orient to.

2.3. Drawings

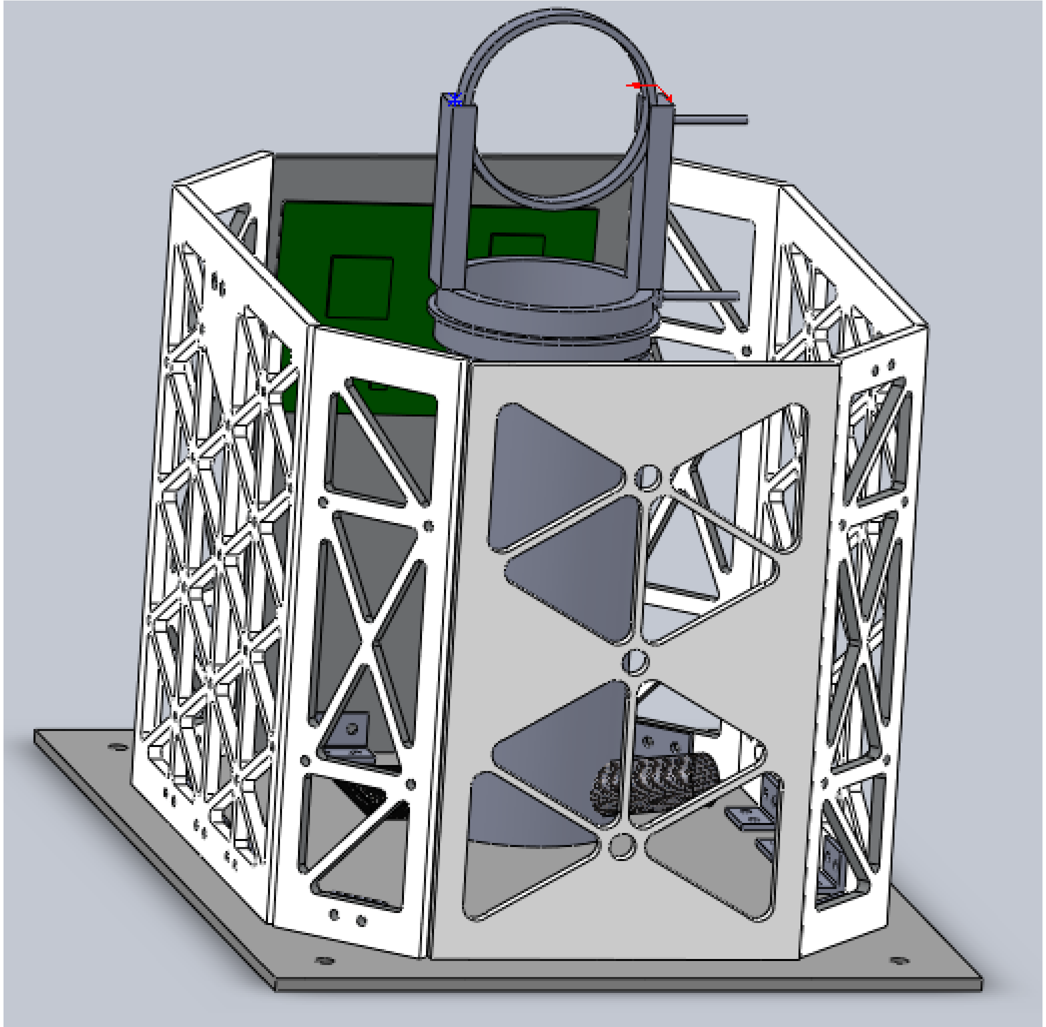


Figure 1: SPARTAN-V Payload Design

Figure 1 shows an initial design for the SPARTAN-V payload. The 9 inch, 1200 mm focal length telescope in the center has a gimbaled mirror mounted above it. The green plate represents the circuit board, which includes the processor and other components that will be needed during flight.

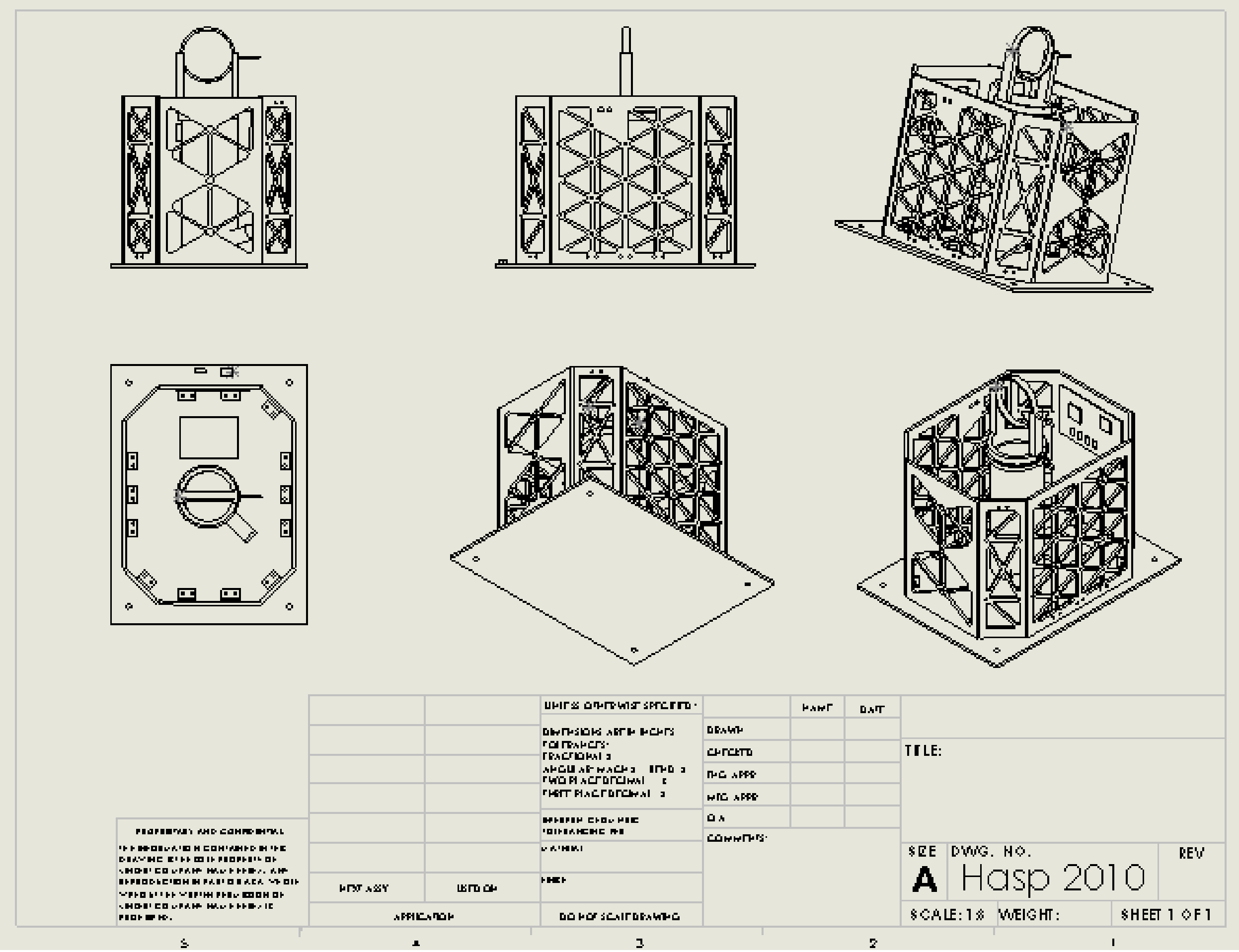
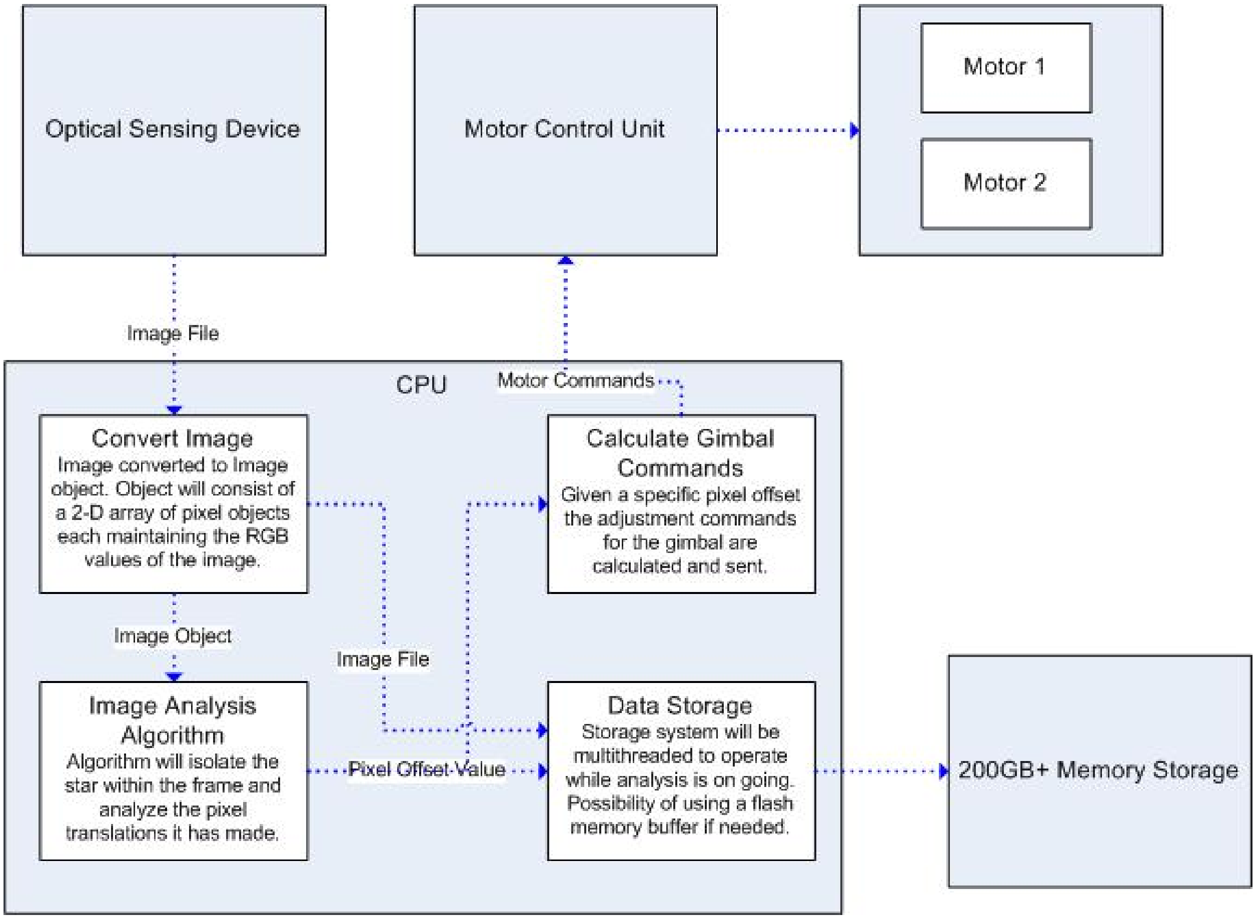


Figure 2: Multiple Angle Views of SPARTAN-V Payload

Figure 2 shows various angles of the SPARTAN-V payload. This height of the total payload is approximately 16 inches, which exceeds the height requirement by 4 inches.

2.4. Gimbal Feedback Loop

The following diagram shows an initial plan for the control system for the pointing system. This feedback loop assumes we have a star acquired in our field of view, and presents a conceptual design of the software and the functionality of the SPARTAN-V system.



2.5. Thermal Plan

The internal temperature of the payload shall remain within the bounds of the operating range of all payload components. No heater is anticipated to be necessary for this goal, as the heat generated by the processor and the power converters will be rather extensive. Therefore the issue lies with the capacity to remove this heat from the payload in order to avoid over-heating, and thus computer shutdown, as any intermittence of data recording would have vast implications towards post-flight data analysis.

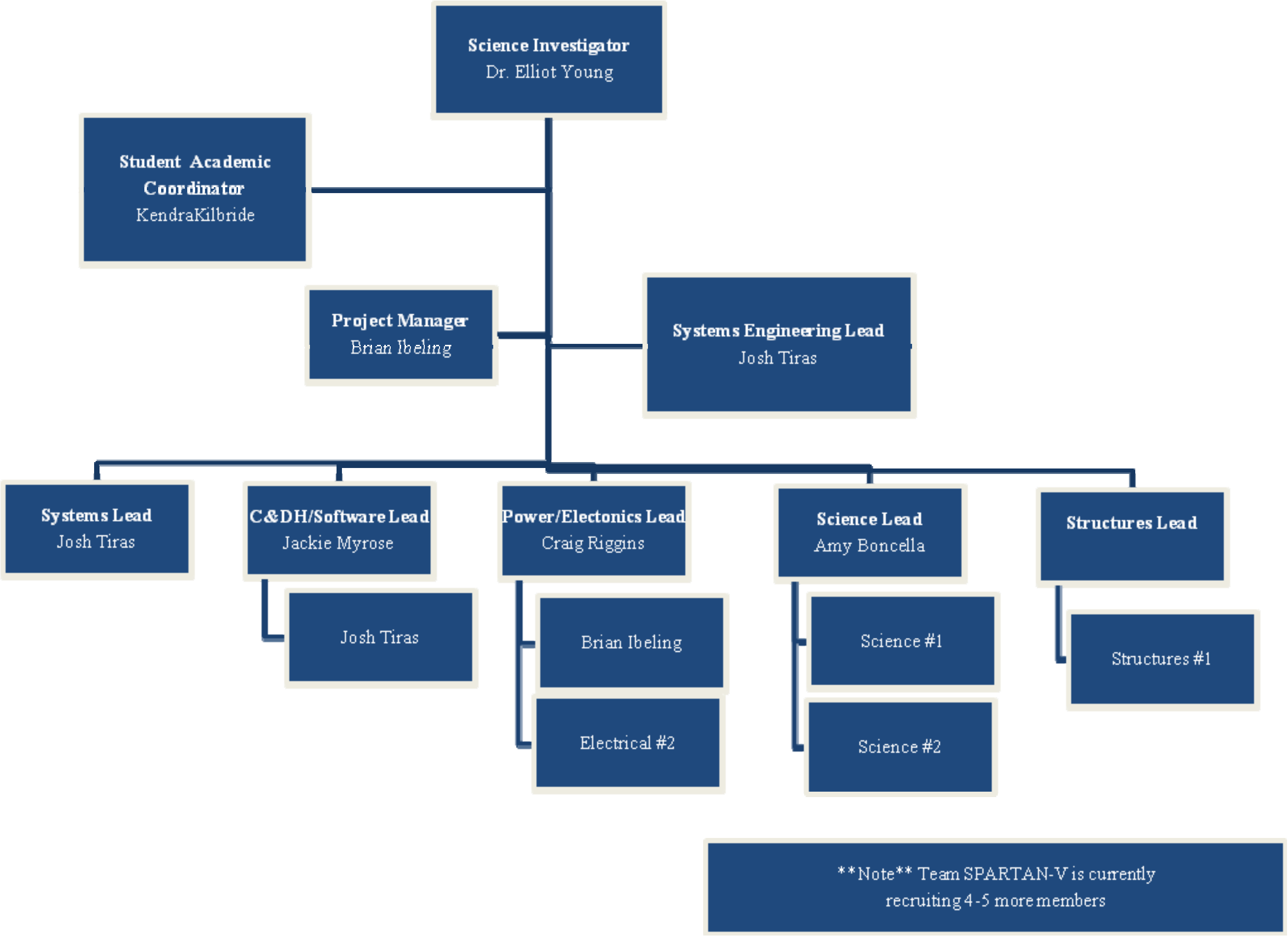
To accomplish this goal, heat-sinks shall be applied to both processors with thermal epoxy. These heat-sinks will not be standard fin design, as those are oriented around distribution of heat to a fluid passing over the fins, specifically air, which will be lacking in the near-vacuum of 120,000 feet. Rather, heat-sinks will be used which conduct thermal energy directly to the payload structure and from the structure radiated to space. In this way SPARTAN-V shall use the HASP platform as a well for heat storage, and as such distribute the thermal energy away from the processor elements to avoid over-heating and forceful shutdown of the system.

Given the success of the internal thermal control, it may be necessary to place a heater externally upon the gimbal system mounted on top of the payload structure in order to maintain the temperature of the CCD camera mounted to the gimbal. As it is not yet certain how the thermal distribution of the processor elements shall perform, further testing will be done to identify whether this external heater shall be necessary.

3.0 Team Management and Scheduling

3.1. Management Chart

The SPARTAN-V team currently consists of five students who have worked on the proposal. The team will likely require upwards of ten total members to design, construct, and test the payload over the course of the spring semester. The team will also be working closely with faculty advisors and science researchers, offering guidance and advice to ensure the payload’s goals are being met.



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3.2. Scheduling

SPARTAN-V will be structured so that meetings with our faculty will occur a minimum of once a week. During these meetings all team members shall be present to discuss the project at all levels. Meetings with technical investigators will occur monthly to ensure that all systems and components are progressing at a satisfactory pace.

Individual team leads will determine when and how often their teams will meet. Team leads will assign common working hours every week to perform research, construction, and testing.

Date	Description
12/18/09	Proposal Due
January-November	Monthly Status Reports and Teleconferences
1/15/10	Results of Proposal Announced (approx)
1/22/10	Conceptual Design Review (CoDR)
2/5/10	Preliminary Design Review (PDR)
3/5/10	Critical Design Review (CDR)
3/17/10	Finalize Hardware Orders
3/31/10	Begin Sub System Construction
4/23/10	Preliminary PSIP document due
4/27/10	Begin Integration
4/20/10	Begin System Testing
5/14/10	Flight Test Simulation
5/21/10	Mission Simulation
5/24/10-5/28/10	Thermal/Vacuum Testing
5/29/10	Finish Integration
6/1/10	Final FLOP document due
6/5/10	Finish Final System test and Fight Simulation testing
8/2/10 – 8/6/10	Student Payload Integration at CSBF
8/28/10 – 9/2/10	HASP Flight Preparation
9/1/10	Target Flight Ready
9/3/10	Target Launch Date

4.0 Integration and Launch

At the Columbia Scientific Balloon Facility, Team SPARTAN-V will have their Systems Engineering Lead, Structures Lead, Power Lead, and C&DH Lead present to begin integration. The Systems Engineering Lead will supervise the operation, making sure each step follows the proper integration procedure. The System Engineering Lead will also connect the necessary wires from HASP to our structure, as well as make sure all systems are operational after integration. The Structures Lead will properly attach the structure to HASP. The C&DH Lead will test communication equipment during integration.

4.1. Interface Specifications

Position	1 Large Student Payload
Approximate Weight	20 kilograms
Mounting Footprint	Complies with provided plate; See Figures 1 and 2
Height	30 cm
Length	40 cm
Width	31 cm
Power	31W (1.15A @ 27 V worst case)
Telemetry Rate	1200 bps
Uplink	4800 Baud

4.2. Flight Procedures

Time	Satellite Subsystem	Function
T- 02:00:00	Computer and Electrical	System: Turn on Enter Hibernation state
T 00:00:00	HASP Launch	Launch
T+ AT (Astronomical Twilight)	System	Activate System Exit Hibernation state
T+ AT + 10:00	Communications	Begin sending data and diagnostic packets
T+ ~25:00:00	Satellite	Satellite Touchdown and Recovery

The SPARTAN-V payload shall be fully automated once a system activate command is sent to the payload. As the SPARTAN-V science mission requires a night time only flight, the payload shall remain in a hibernating state during the day hours of flight. Once astronomical twilight is reached, a command will be sent to the payload to initialize all systems and begin primary program sequences. Once the payload confirms successful system activation, the SPARTAN-V mission operations team will send a command to initialize the Star Acquisition sequence. The payload will confirm the completion of this sequence and begin to send data and diagnostic packets approximately every fifteen minutes. The mission operations team will analyze these packets in order to confirm the orientation of the pointing system and that all devices are operating appropriately. Should the pointing system require re-orientation, the mission operations team will send the command to begin the Star Acquisition sequence and attempt to re-orient the payload. This command will be sent as needed during flight, to be determined by the mission operations team’s analysis of the data and diagnostic packets. If the SPARTAN-V payload should fail to confirm system activation, the mission may fail, as the only recourse they mission operations team will have is to retry the system activation command.

5.0 Conclusion

The primary goal of the SPARTAN-V payload is to further characterize the environment seen by high altitude observatories. By developing a pointing system to allow us to analyze the variations in brightness of a star, the SPARTAN-V payload will be able to provide sufficient information to verify the feasibility of a student-built pointing system on a high altitude observatory.