

HASP Student Payload Application for 2019

Payload Title: Small Mounted Optical Lens Dual-camera Experimental Remote-sensor (S.M.O.L.D.E.R.)		
Institution: Arizona State University		
Payload Class (Enter SMALL, or LARGE): Small	Submit Date: December 14, 2019	
<p>Project Abstract: As wildfires exacerbated by climate change continue to devastate the western United States, assessment of fire susceptibility becomes increasingly vital. S.M.O.L.D.E.R. proposes a payload system that aims to answer the following questions:</p> <div style="margin-left: 40px;"> (1) Can vegetation indices be used as a proxy for determining desert drought conditions? (2) How well do vegetation indices correlate to rainfall? </div> <p>This payload will capture reflectance spectroscopy imagery in the red and near-infrared range. These spectra will be used to calculate vegetation indices NDVI and MSAVI-2 (see section 1) as an approximation of plant health. This data will be compared to climate data along the flight path to map vegetation indices to rainfall data. The result of this project is a trial and optimization/critique of diagnostic tools in the unique ecosystems of the American Southwest.</p> <p>The SMOLDER payload will conform to a 5.25" x 5.5" x 8.125" container and will weigh less than 2 kilograms. Current interface requirements include 5.1 Watts of power and 26 bps of downlink bandwidth.</p> <p>The team is composed of seven students from the School of Earth and Space Exploration, each assigned responsibility for at least one project subsystem.</p>		
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1 Payload Description

1.1 Scientific Objectives and Justification

This project is motivated by a recent uptick in large-scale forest fires provoked by climate change. It has become apparent that scientists and public communities alike need better metrics through which to measure their susceptibility to large fires. This project aims to determine whether remote sensing data can be used as one such proxy for desert drought conditions and thus fire risk.

As stated in the abstract, this project will ask two questions:

- 1: Can vegetation indices be used as a proxy for determining desert drought conditions?
- 2: How well do these vegetation indices correlate to desert rainfall?

Question 1 attempts to research the utility of vegetation indices beyond their typical use. While vegetation indices are frequently used to assess vegetation health alone (Saltz et al) there is an interest in the use of vegetation indices to diagnose the particular effects of climate change on ecosystems (Breshears et al, Ingram et al, Tucker et al, etc.). Question 1 is in the spirit of these other investigations, and attempts to utilize vegetation indices and vegetation indices alone to judge the ecological health of a region. Question 2 aims to investigate the relation of these indices to other metrics of drought, particularly rainfall records. In order to use vegetation indices to assess ecological health and fire susceptibility, it is important to see how these new methods correlate (or don't correlate) to the most popular traditional methods like rainfall records.

Thus, the SMOLDER team proposes a payload that will use remote sensing techniques to determine the presence and health of vegetation across the HASP flight path. During sunlight hours, the payload will gather spectroscopic data from the ground below. The science payload will include two Raspberry Pi NoIR digital cameras pointed at the ground that will record reflectance values in the red and near infrared wavelengths.

Spectral analysis studies have shown that healthy vegetation has a high reflectance in the near infrared wavelengths and low reflectance in the red wavelength (i.e. Lloret et al). This spectral feature can be used to assess plant health by computing vegetation indices. The most fundamental vegetation index is a band ratio of near infrared reflectance over red reflectance. However, a more effective index of plant health is the Normalized Difference Vegetation Index (NDVI), which uses differences of the reflectance values with: $NDVI = \frac{NIR-red}{NIR+red}$, where positive values indicate plant vitality, and values close to or less than zero indicate lack of plant cover or unhealthy plants, respectively. Another vegetation index is the Modified Soil-Adjusted Vegetation Index (MSAVI2), an index designed to perform more accurately for arid plant ecosystems. The MSAVI2 equation is: $MSAVI2 = \frac{2*NIR+1-\sqrt{(2*NIR+1)^2-8(NIR-red)}}{2}$. Looking at the change in these two indices over time and correlating them to rainfall data taken by the National Weather Service, these tools can be used to determine drought conditions and assess fire risk.

1.2 Payload Systems Review

1.2.1 Thermal

Based on previous HASP flight data, the gondola will experience a temperature range of -55 °C to +25 °C. Each hardware component aboard the payload has an operational temperature range within the bounds of these anticipated environmental conditions: the Raspberry Pi NoIR v2 cameras operate between -20 °C and -60 °C and the automatic DC-DC buck boost converter operates from -40 °C to 85 °C; however, the Raspberry Pi 3 B+ board has an operational temperature range of 0 °C to 50 °C. Though previous ASU HASP teams have flown identical hardware under similar conditions without trouble, the team plans to perform thorough thermal testing on the hardware to ensure proper function. Based on the results of the thermal testing, the team may choose to purchase a small heater to keep the payload's internal environment at a suitable operating temperature for the Raspberry Pi board. Additionally, the team will coat the payload with a thermally resistant material and the internal components will be separated from the payload panels with standoffs.

1.2.2 Mechanical

The payload container will be constructed using 1/8" aluminum panels held together with exterior and interior brackets. A detailed diagram of each payload face can be found in section 4.1 of this application. The electrical, computer, and sensor subsystems will all be configured and mounted within the payload container. Items to be mounted to the mechanical subsystem include the DC/DC converter, raspberry pi computer, and the dual-camera system, as shown in figure 1 below.

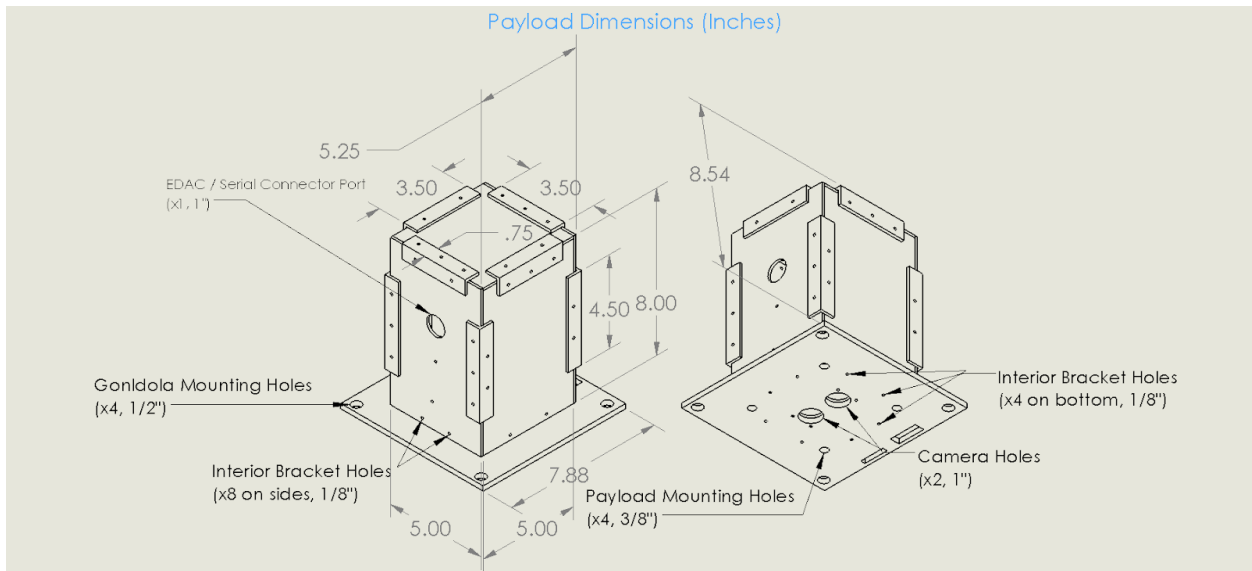


Figure 1: Labeled payload diagram

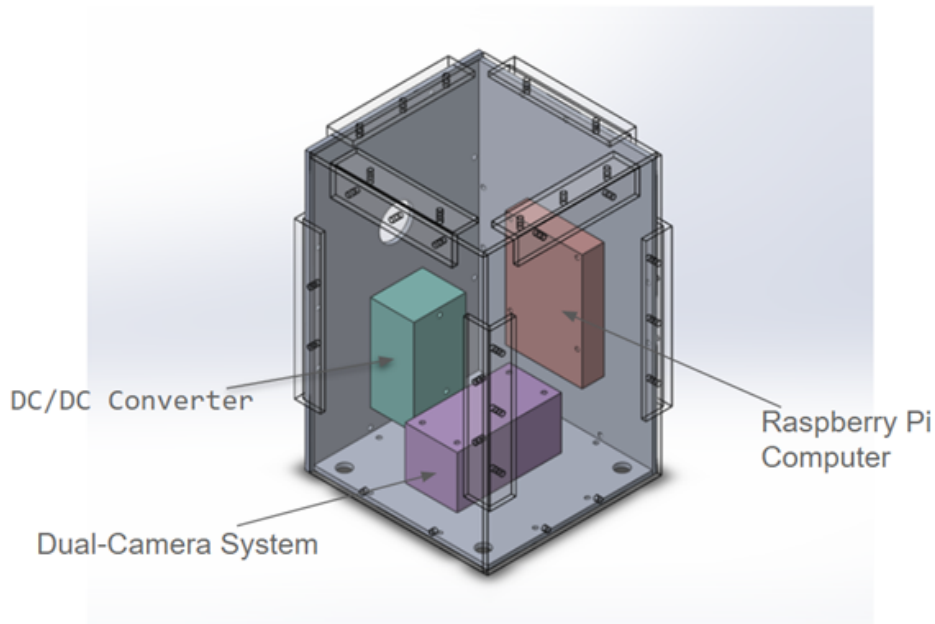


Figure 2a: Payload interior diagram

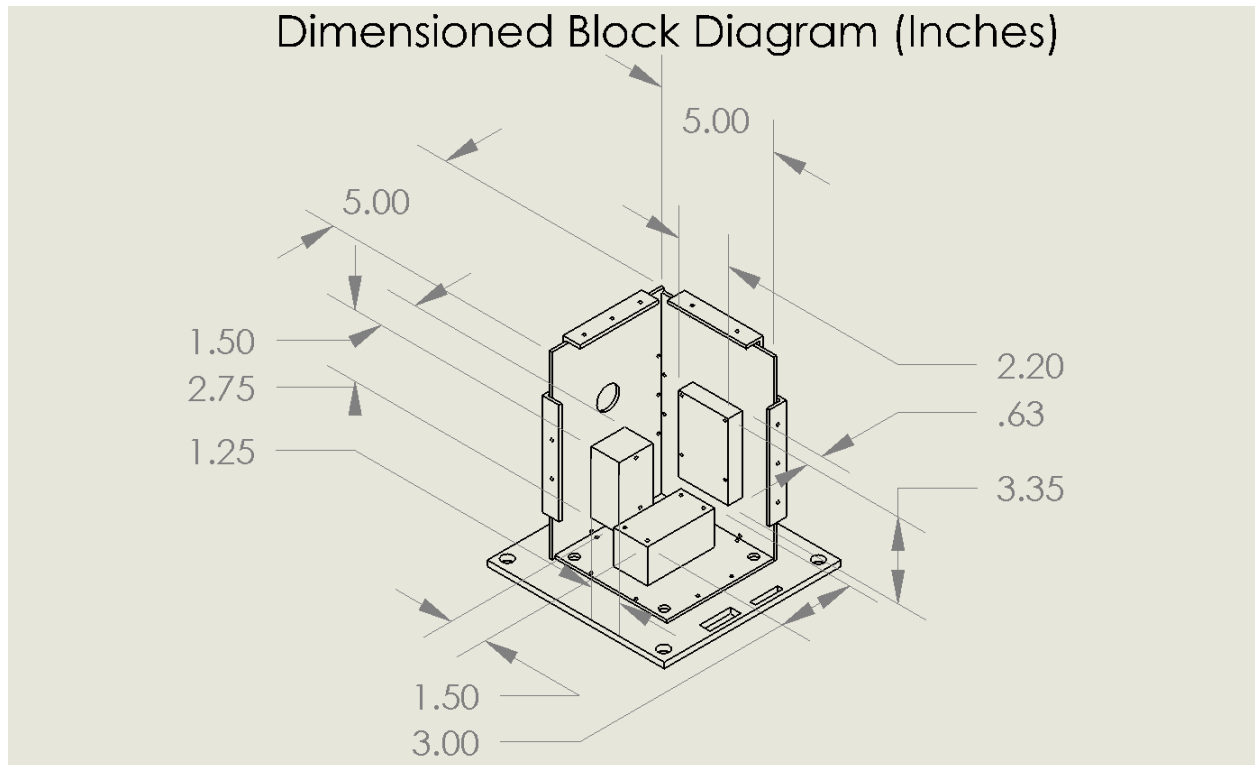


Figure 2b: Dimensioned block diagram of payload exterior

1.2.3 Electrical

HASP will supply +30 volts of direct current power to the gondola via a 20-pin EDAC516 connector. A DROK DC-DC Automatic Buck Boost Converter will convert the supplied current into a form usable for the Raspberry Pi 3 B+ board. Previous ASU payloads have flown this same model of converter twice before without problem, so the team is confident in the performance of this equipment.

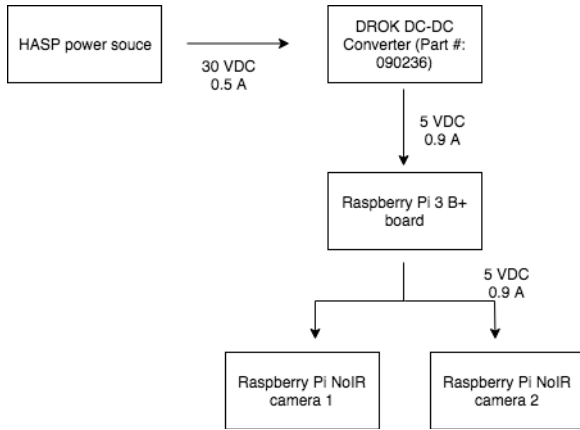


Figure 3: Electrical subsystem block diagram

1.2.4 Computer/Software

Upon initialization, the Raspberry Pi will boot up and load the operating system (OS). Once the OS is loaded, the capture program will start a time-delayed countdown determined by ascent speed, which will stall image capture until the gondola reaches altitude. After the initialization of the time delay, a secondary monitoring program will also begin to fail-safe the delay program. Once the payload reaches flight altitude (~36 km) and the countdown terminates, the dual Raspberry Pi NoIR cameras will begin to acquire images, each camera taking a picture once every sixty seconds. These images will be transferred to the on-board micro SD card as raw RGB files. Upon freeze/crash of the primary program, the secondary monitoring program will restart the primary program without time delay. If both the primary capture program and the secondary monitoring program crash (determined by absence of transmission for more than 60 seconds), a power cycle code will be sent to restart the Raspberry Pi.

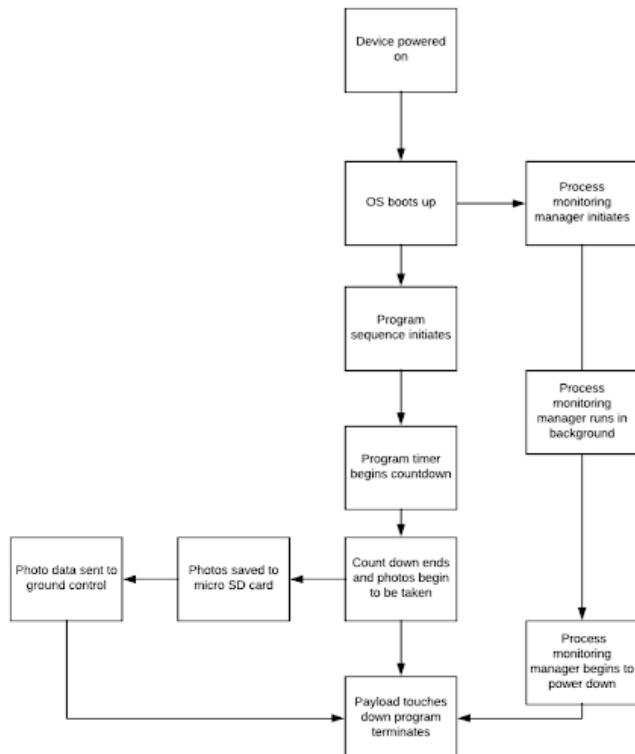


Figure 4: Computer subsystem block diagram

1.2.5 Sensor

The sensor subsystem will consist of two cameras attached to the Raspberry Pi mainboard via an I/O board. Each camera will be modified with aftermarket lenses to provide the appropriate field of view at altitude. Each camera will have a waveband filter corresponding to the wavelengths needed for the vegetation indices: a red filter with a center wavelength of 650 nanometers (± 15 nm) and a full width-half maximum (FWHM) value of 80 nanometers (± 25 nm), and a near IR filter with a center wavelength of 850 nanometers (± 3 nm). To achieve the desired FWHM of 140 nanometers (± 5 nm), the team will purchase a custom near infrared filter. The sensor system will be calibrated before flight to provide an accurate radiometric calibration. Bayer filter response will also be tested to ensure accurate demosaicing and analysis. The cameras will be mounted vertically, pointing downward to view the landscape beneath the gondola.

The sensor system will capture 10-bit RGB raw values, bypassing the onboard processing and saving the sensor values directly. These images will be taken and stored on the SD Card during flight at rate of two images per minute. After recovery, the team will apply a custom calibration and demosaicing procedure to obtain the radiometrically calibrated data products for analysis. This calibration will allow the team to compare the data acquired in-flight to other remote sensing data such as Landsat imagery. For all images taken with the red filter, the team will use only the red pixels from the BGGR Bayer pattern and use an interpolation algorithm to fill in the missing values. For images taken using the near infrared filter, the team will use all pixels, since the spectral response at this wavelength will be the same for all pixels, effectively creating a grayscale image that does not required debayering.

The following process will be used to obtain a calibrated product from the raw data to use in the data analysis phase:

For the red (650 nm) image: debayer \rightarrow red channel \rightarrow dark current removal \rightarrow flat field correction \rightarrow radiometric calibration

For the near infrared (850) nm image: combine RGB channels \rightarrow dark current removal \rightarrow flat field correction \rightarrow radiometric calibration

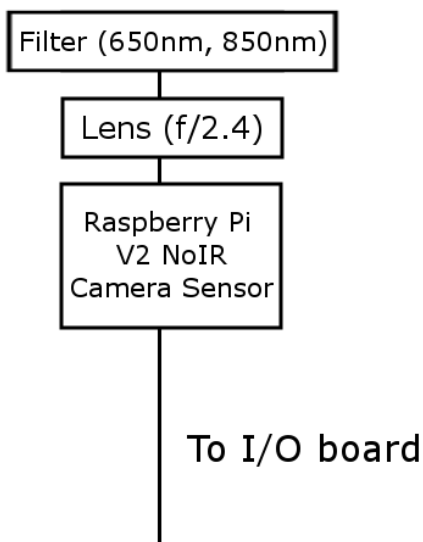


Figure 5: Sensor subsystem block diagram

1.2.6 Data

This section will discuss both the data stored on board on the SD card and the telemetered data. See **Section 3.4** for further details.

On-board Data:

Each camera will take one image every sixty seconds. These images will be taken within milliseconds of each other and subsequently transferred to the on-board SD card and saved in raw RGB format. This will allow for the images to be saved in an uncompressed format, preserving the collected data in its entirety. Currently, the team has two potential plans for image acquisition. Plan 1 involves initializing the system once the gondola has reached altitude (initialization at $T = \sim +2$ hours) and leave the system running for six hours, powering down once the Sun has set (shut down at $T = \sim +8$ hours). For this plan, the team anticipates a total of 720 images. System initialization for plan 2 would occur at launch ($T = 0$) and system termination would take place at the HASP-appointed shut-down time ($T = \sim +17.5$ hours), resulting in 2100 images total; however, the team would likely throw out images from the first two hours of flight due to lack of relevance to the project, reducing the number to 1860 images. The team can calculate the range of data storage for images: 8.93 GB – 26.1 GB. **See appendix 1 for calculation.** After the flight, images will be converted to PNG format for data processing.

Telemetered Data:

Telemetry will be transmitted over an RS232 serial connection at a bitrate of 1200 baud, using 8 data bits, no parity, one stop bit, and no flow control. Including the start bit, this is 10 bits per byte. All information will be sent using these settings, and so the telemetry will be split up into multiple byte-sized chunks. The team will use a Trendnet TU-S9 USB serial converter for this communications port. A single set of telemetry is considered a record, with a size defined by the sum of the telemetry elements below. The final record size is 1540 bit, and the team plans to send this record with each image acquisition (once per minute), meaning an average data rate of 26 bps. After 100 records are received, they are placed into a file and made available for the team to access via the HASP flight info website. The team does not anticipate the need for any additional uplink commands beyond the HASP power-on/power-off commands (which are controlled automatically by the EDAC), only downlinked telemetry. The table below (figure 6) details the specifications of the telemetered data.

Byte	Title	Description
1-2	Header	Denotes the beginning of record
3-16	System Timestamp	UNIX timestamp of the Pi
17-136	GPS Data String	Obtained periodically from gondola
137-140	Most Recent Filename	Assuming '0000.jpeg', naming scheme
141-150	Used Storage	Total amount of data stored in kB
151-152	Checksum	Used to ensure an accurate record
153-154	Footer	Denotes end of record

Figure 6: Telemetry data specifications

1.3 Principle of Operations

Before flight, the system will be calibrated at an Arizona State University lab. The team will perform an absolute radiometric calibration including a dark frame assessment, flat field calibration, and photon transfer and linearity to correct noise biases, lens roll-off, and to show that the sensor has linear response with exposure time. After calibration, the team will perform a thermal vacuum chamber test on the payload, during which the payload will be exposed to temperatures ranging from -55°C to 25°C. These temperatures were chosen to simulate the range of temperatures the payload will experience during ascent. Once thermal vacuum testing is complete, the team will assess the payload for any damage – physical or technical – and will make any necessary repairs. Afterwards, select team members will attend the HASP integration to mount the payload to the HASP gondola and test to see if the electrical components work properly. During integration, the team will connect the electrical interfaces of the payload to the gondola. The team will then power on the payload to check for any damage that may have occurred during travel. Additionally, the team will run a test version of the data acquisition program designed to check power draw, image acquisition and storage, and serial transmission. In this same time frame, the team will assess the mechanical interface of the payload and the gondola. Between system integration and launch, HASP will perform a final hang test (if necessary) and conduct a mission readiness review, during which time the team will need to demonstrate that the payload is ready to fly.

On launch day, the team will initialize the system at the designated time (see section 3.4 or appendix 5.1 for more details). The payload will then collect, store, and transmit data for the duration of the flight, until the power down signal is sent out by HASP. After the payload has descended, been retrieved, and shipped back to Arizona State University, the team will perform data analysis on the images by comparing the spectral reflectance in the red and near IR wavelengths to calculate vegetation indices. The team will also compare flight data to weather data taken at weather stations along the flight path to attempt to correlate vegetation indices to drought conditions. **A complete concept of operations can be found in appendix 5.1.**

2 Team Structure and Management

2.1 Team Structure

Team Member	Position	Position Description/Responsibilities
Jenna Robinson	Systems Engineer	<ul style="list-style-type: none">• Ensure that team completes assigned tasks by the appointed deadline• Sign off on all system designs and materials requests before submission• Act as a liaison between student team and faculty advisor
	Data Subsystem Lead	<ul style="list-style-type: none">• Develop code to process images post flight• Distribute post-processed images to appropriate recipients
Paras Angell	Science Subsystem Lead	<ul style="list-style-type: none">• Establish spectral and spatial resolution requirements• Ensure that experiment designs meet resolution requirements
Megan Bromley	Testing Officer	<ul style="list-style-type: none">• Schedule and oversee system testing, including, but not limited to: calibration, thermal vacuum chamber testing, vibration testing, shock testing
Henry Cardamone	Mechanical Subsystem Lead	<ul style="list-style-type: none">• Use SolidWorks to design payload container• Collaborate with machine shop to oversee payload building process

	Project Treasurer	<ul style="list-style-type: none"> • Keep track of project budget (weight, volume, power, and cost)
David Lewis	Sensor Subsystem Lead	<ul style="list-style-type: none"> • Ensure that sensor systems meet science requirements • Research and select appropriate hardware • Define software requirements for hardware calibration and image analysis
Timothy McMillen	Electrical Engineer	<ul style="list-style-type: none"> • Design, build, and maintain electrical system • Ensure the safety of group members and equipment while dealing with electrical systems
	Schedule Master	<ul style="list-style-type: none"> • Operate SCRUM meetings as SCRUM master • Maintain backlog
Michael Oals	Software Engineer	<ul style="list-style-type: none"> • Develop code for in-flight operations (system initialization, image acquisition, debug) • Monitor payload in-flight to ensure proper function, debug as necessary

It is anticipated that two to three members (designated in bold in the table above) will participate in integration at CSBF and flight operations at Ft. Sumner.

2.2 Schedule

The team will be operating on three six-week long sprints for the build phase of the project, with each sprint having a different theme assigned to it. This work style is advantageous because it will allow the team to focus on building iterations of the project rather than trying to build it all at once. A sprint approach will also allow the team to better react to any changes that will need to occur during the build, as each sprint builds off of the progress of the previous one.

The sprint themes will be as follows:

1. Prototype Construction: During this sprint, the team will make the first iteration of the mechanical and technological systems needed for the mission.

2. Prototype Second Iterations: The first series of software and sensor calibration tests will occur at the beginning of this sprint, with adjustments made as necessary.
3. Stress Test First Round: During this sprint, the team will perform stress testing in the thermal vacuum chamber and weather testing on equipment.
4. Prototype Third Iteration: This sprint will be dedicated to making any necessary design adjustments after testing.
5. Field Testing: Field testing of the payload, proving that all systems will perform as expected outside of the lab, will occur during this sprint.
6. Final Touches: In this last sprint, the team will make any final adjustments to the payload, as well as constructing a back-up payload, both of which will be sent to HASP for integration and flight operations.

HASP deliverables underlined; * denotes HASP variable deadlines

Month (2019)	Deliverables
January	Team meeting (1/7)
	Team meeting (1/14)
	Mechanical, software, and hardware prototypes complete (1/25)
	<u>Monthly Status Report (1/25)</u>
	Team meeting (1/28)
February	<u>Monthly Teleconference (2/1)</u>
	Team meeting (2/4)
	Team meeting (2/11)
	Software testing and sensor calibration (2/15)
	Team meeting (2/18)
	<u>Monthly Status Report (2/22)</u>

	Team meeting (2/25)
March	<u>Monthly Teleconference (3/1)</u>
	Team meeting (3/4)
	Thermal vacuum chamber testing and weather testing (3/8)
	Team meeting (3/18)
	Team meeting (3/25)
	Mechanical, software, and hardware prototype second iterations complete (3/29)
	<u>Monthly Status Report (3/29)</u>
April	Team meeting (4/1)
	<u>Monthly Teleconference (4/5)</u>
	Team meeting (4/8)
	Team meeting (4/15)
	<u>NASA On-site Security Clearance Document (4/15)</u>
	Team meeting (4/22)
	Field testing (4/19)
	<u>Preliminary Payload Specification and Integration (PSIP) Document; Monthly Status Report (4/26)</u>
	Team meeting (4/29)
May	<u>Monthly Teleconference (5/3)</u>
	Team meeting (5/13)
	Team meeting (5/20)

	Back-up payload construction complete (5/24)
	Team meeting (5/27)
	<u>Monthly Status Report (5/31)</u>
June	<u>Monthly Teleconference (6/7)</u>
	Team meeting (6/10)
	Team meeting (6/24)
	<u>Final PSIP Document; Monthly Status Report (6/28)</u>
July	<u>Monthly Teleconference (7/5)</u>
	Team meeting (7/8)
	<u>Payload Integration (7/15-7/19)*</u>
	<u>Final FLOP (7/19)</u>
	Team meeting (7/22)
	<u>Monthly Status Report (7/26)</u>
August	<u>Monthly Teleconference (8/2)</u>
	Team meeting (8/5)
	Team meeting (8/19)
	<u>Monthly Status Report (8/30)</u>
	<u>HASP Flight Preparation (8/29-8/30)*</u>
	<u>Target Flight Ready (8/30)*</u>
September	<u>Target launch date & flight operations (9/2)*</u>
	<u>Recovery, packing, and return shipping (9/5-9/8)*</u>

	<u>Monthly Teleconference (9/6)</u>
	<u>Monthly Status Report (9/27)</u>
October	<u>Monthly Teleconference (10/4)</u>
	<u>Monthly Status Report (10/25)</u>
November	<u>Monthly Teleconference (11/1)</u>
	<u>Monthly Status Report (11/29)</u>
December	<u>Final Flight/Science Report (12/6)</u>

3 Payload Specifications

3.1 Payload Volume and Weight Budget:

Component	Mass (g)
B/W Raspberry Pi Camera (x2)	6
DC/DC Converter	150
Raspberry Pi 3 Model B	50
Raspberry Pi USB Connector	10
Raspberry Pi Multicamera Adapter	15
256 GB MicroSD Card	2
Filters (x2)	10
USB Serial Converter	40
Housing Unit & Hardware	1500
Total	1783 ± 250

An uncertainty of 250 grams accounts for the unknown (as of yet) mass measurements of all the small hardware components that will be used to build the housing unit (screws, spacers, wires, washers, etc.). Even with this uncertainty or greater, the payload still comes in under the allowed small payload weight budget of 3 kilograms.

The payload container will have the following dimensions: 5.25” x 5.5” base and 8.125” height. This falls well within the size constraints of a small HASP payload.

3.2 Mounting Plate Footprint:

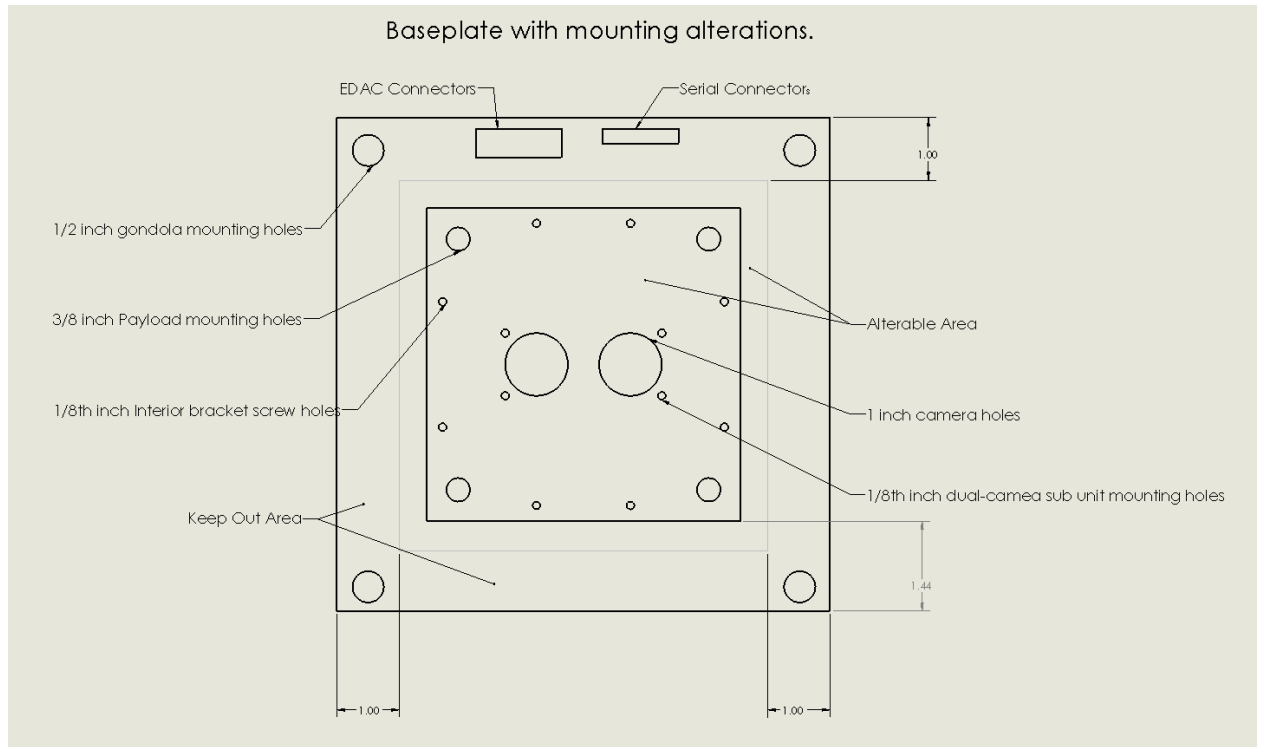


Figure 7: Annotated mounting plate footprint

3.3 Power Budget:

Component	Power Draw (W)
B/W Raspberry Pi Camera (x2)	2
DC/DC Converter	0.75
Raspberry Pi 3 Model B	1.75
Raspberry Pi USB Connector	0
Raspberry Pi Multicamera Adapter	0
256 GB MicroSD Card	0.01
Filters (x2)	0
Housing Unit & Hardware	0
Total	4.51

The total above (4.51 Watts) represents a nominal power draw. At its peak – 400% CPU – the Raspberry Pi 3 B+ will require 5.1 Watts. This peak power draw is most likely to occur during the system initialization phase of the experiment, and it should not present an issue during flight. To convert the supplied voltage into usable power for the Raspberry Pi 3 B+, the team will use a DROK DC-DC Automatic Buck Boost Converter.

3.4 Data Requirements (Total storage capacity, estimated storage use in-flight, downlink and uplink command rates, anticipated use of analog downlink channels and additional discrete commands)

The payload will contain a 256 GB on-board microSD card. Based on calculations shown in appendix 1, the minimum estimated storage use is 8.93 GB and the maximum estimated storage use is 26.1 GB, depending on the chosen image acquisition plan (as discussed in section 1.2.5).

To ensure that the payload functions as intended, the team will send image analytics from the gondola to the ground. The team chose not to send back an image as part of the data analytics because with the average file size of 7.56 MB, at the maximum allowed downlink rate, the image would take approximately 15 hours to transmit (**see appendix 2 for calculation**). Since the whole flight typically lasts 18 hours, sending an image back does not make sense to ensure system function. These analytics will include: most recent filename, most recent file size, GPS location of the last file, and the total storage use. Using the calculation discussed in appendix 1, the team can calculate the total number of files.

3.5 Desired Payload Location and Orientation:

The payload must be oriented with both sensor systems facing down towards the ground; otherwise, position has no constraint on the science objective of the mission. Any of the eight possible small payload locations on the gondola are therefore acceptable for the SMOLDER payload, as shown in figure 7 below.

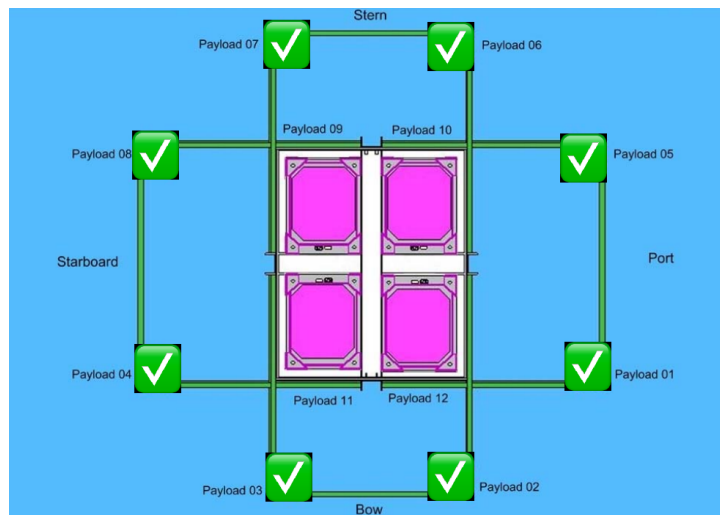


Figure 8: Desired payload location diagram

3.6 Integration Procedures

The team plans to perform thorough integration and payload testing, including thermal vacuum, vibration, and shock testing, before arriving at CSBF. During these tests, the team will ensure that the power draw does not exceed the allowed capacity, that the payload collects, stores, and transmits data without issue, and that all payload components survive the simulated experiment environment. Assuming the payload passes all of these tests, integration at CSBF will consist of proving to HASP personnel that the payload meets the requirements for its given payload class. The team members present at integration will also have a back-up payload to use in case of primary payload failure.

3.7 Potential Hazards

This project does not contain any materials labeled hazardous by the HASP guidelines; therefore, this project has no hazards.

4 Preliminary Drawings

4.1 Dimensioned Payload Drawing (Measurements in inches)

Figures 9-12 below are dimensioned drawings of the payload, with outer dimensions of 5.3" x 5.5" x 8.125". A payload of this volume falls within the maximum payload dimension constraints of 5.875" x 5.875" x 9.843". The three interior components – the DC-DC converter, the Raspberry Pi computer, and the dual camera assembly – all fit comfortably within the payload.

The dimensioned drawings reference all required mounting holes.

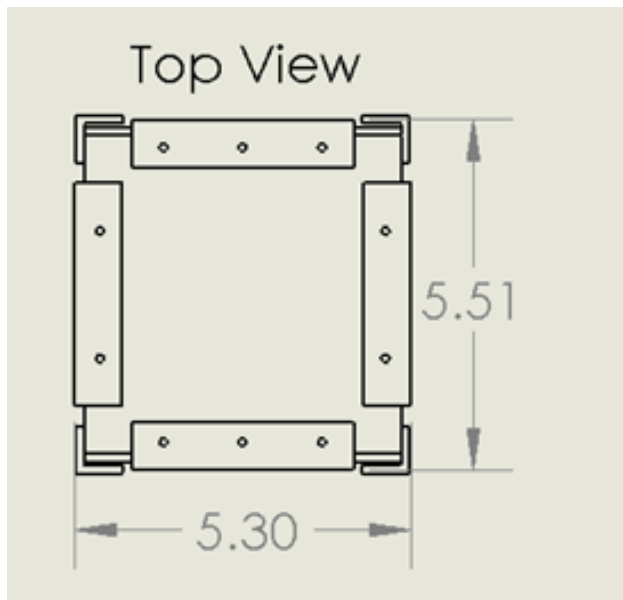


Figure 9: Payload top view

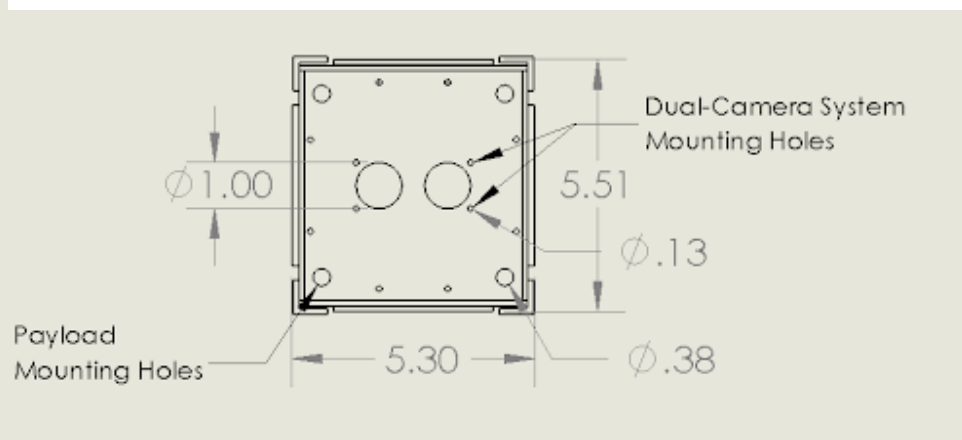


Figure 10: Payload mounting holes

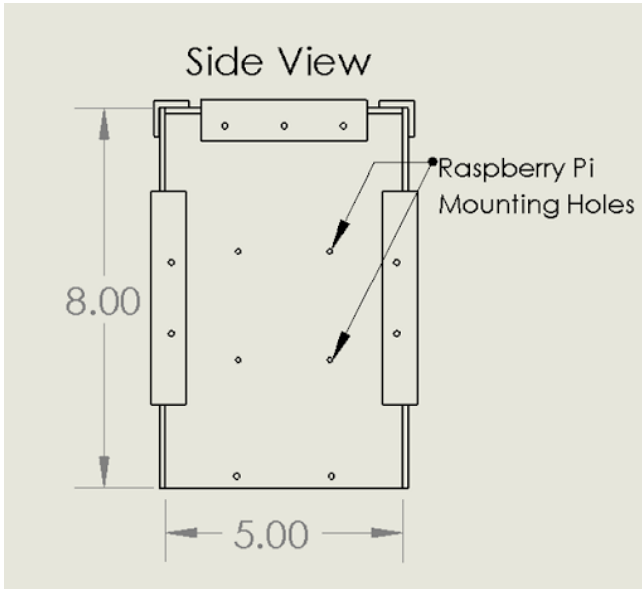


Figure 11: Payload side view 1

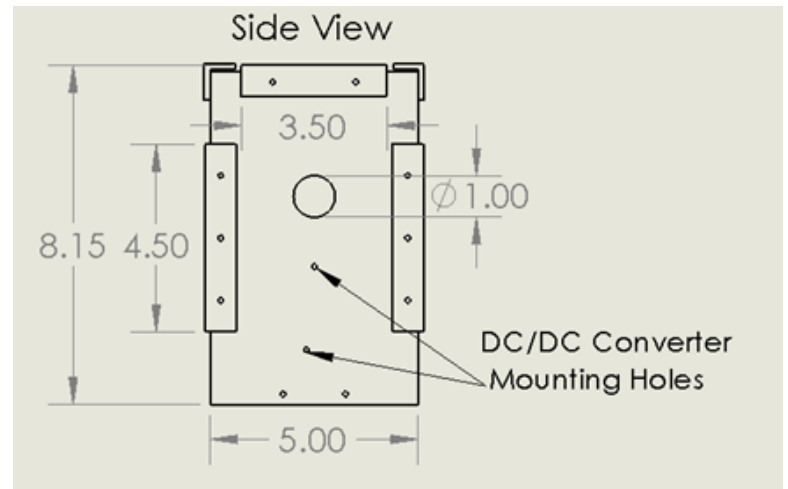


Figure 12: Payload side view 2

4.2 Power Circuit Diagram

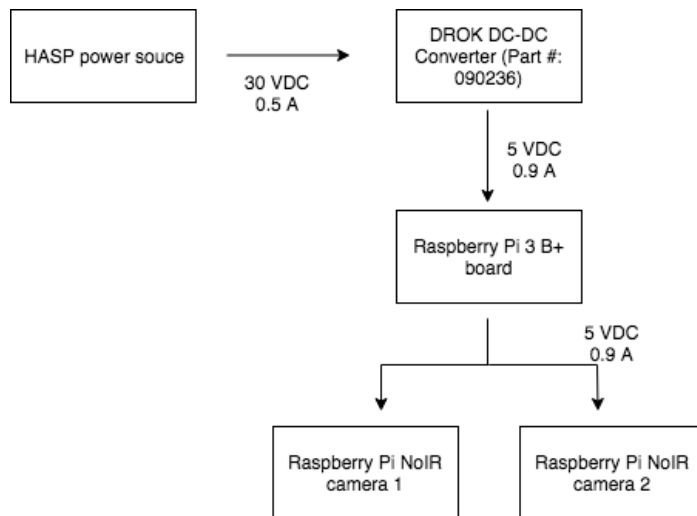


Figure 13: Power circuit diagram with labeled power flow through the system

4.3 Anticipated Payload Mounting Plate Modifications

Eight 1/8th inch holes will be drilled into the mounting plate to account for the inner brackets holding the baseplate and camera unit to the rest of the payload. Two 1-inch diameter holes will allow for the cameras to see the ground below. Four additional 1/8th inch holes secure the dual-camera assembly.

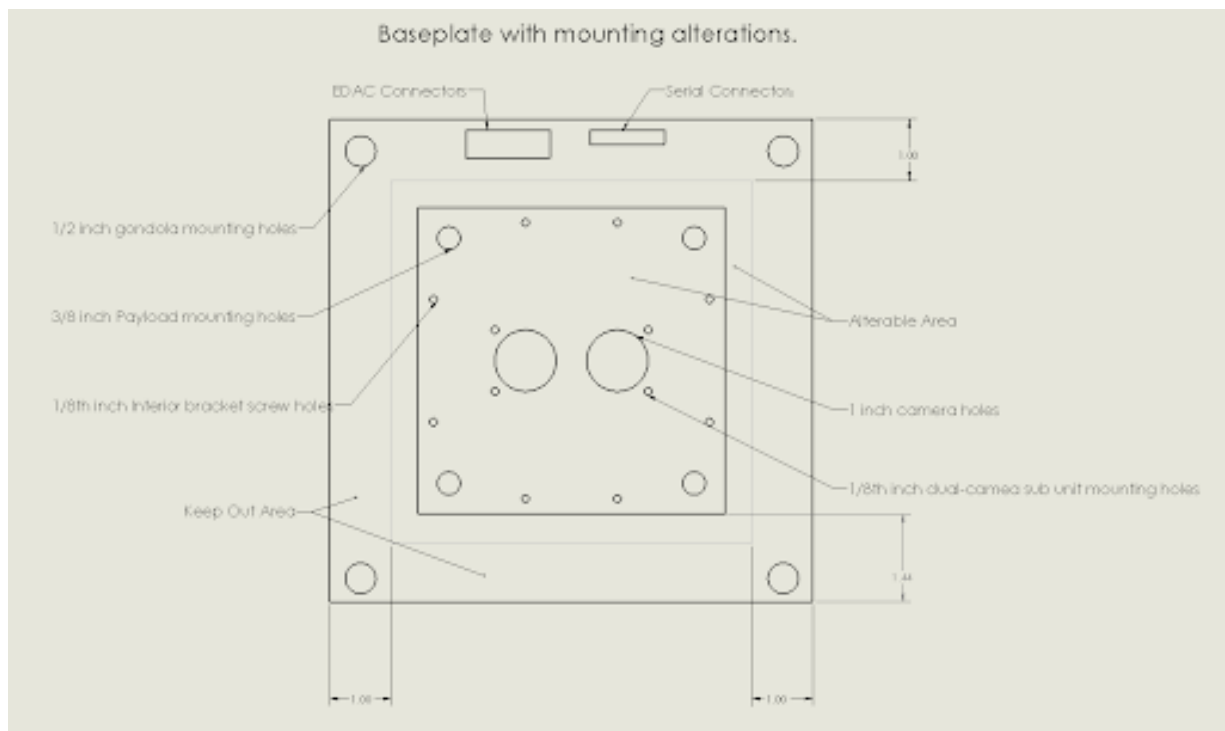


Figure 14: Payload mounting plant modifications

4.4 Mounting Structure

The payload will attach to the mounting plate using four 3/8" countersunk bolts, in the same fashion that the mounting plate is attached to the gondola itself. The mounting plate will be bolted on the gondola with four 1/2" holes.

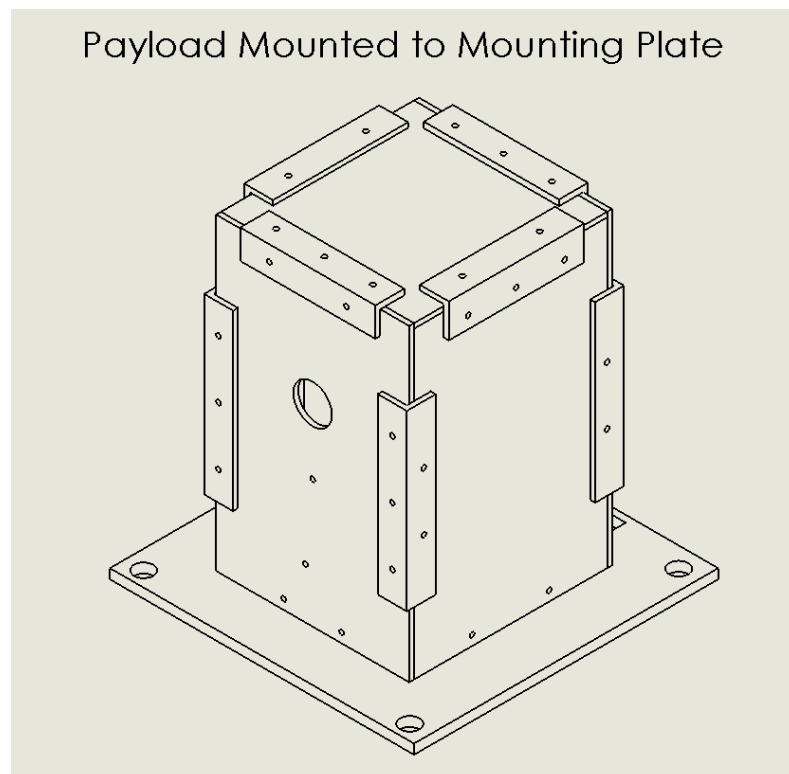


Figure 15: Payload mounting diagram

5 Appendices

5.1 Appendix 1: Data Volume Calculation

Bayer captures using the Raspberry Pi v2 camera can only occur at the maximum resolution, 3280 pixels by 2462 pixels; however, these values are rounded up to the nearest 32 for horizontal and 16 for the vertical, making the resolution 3296 pixels by 2464 pixels.

The data for each Bayer capture takes up 10,270,208 bytes and is appended at the end of the RGB capture. The total file size is the sum of the un-encoded RGB capture plus the Bayer data.

$$\text{Resolution} = 3296 \times 2464 \times 3 \text{ bits for RGB} = 24364032 \text{ bits} \div 8 = 3,045,504 \text{ bytes}$$
$$10,270,208 + 3,045,504 = 13,315,712 \text{ bytes} \div 1024 \div 1024 = 12.699 \text{ MB}$$

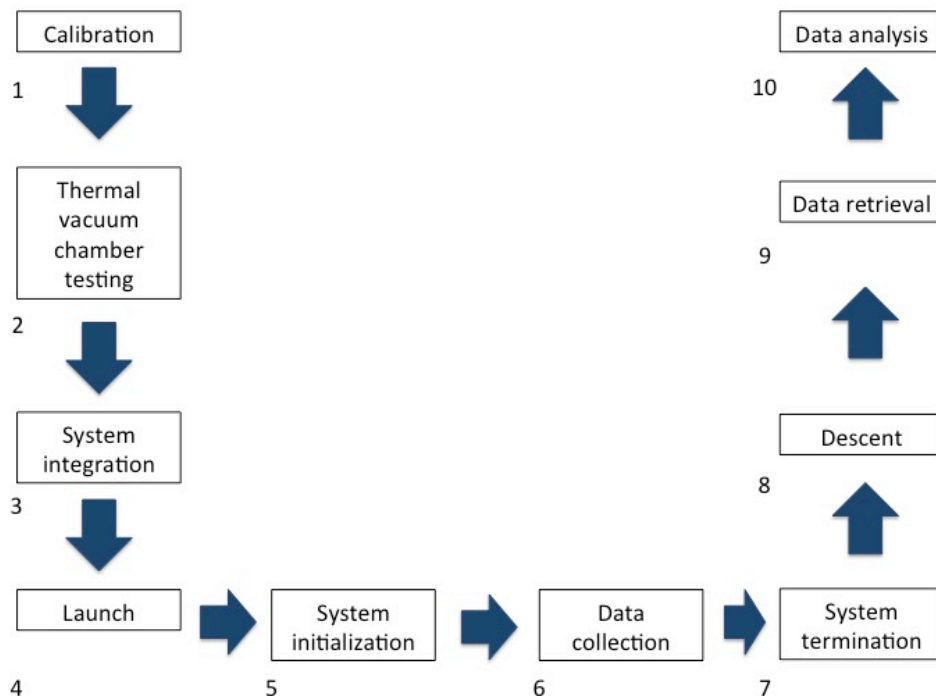
Minimum (720 Images):

$$12.699 \text{ MB} \times 720 = 9,143.28 \text{ MB} = 8.93 \text{ GB}$$

Maximum (2100 Images):

$$12.699 \text{ MB} \times 2100 = 26,667.90 \text{ MB} = 26.04 \text{ GB}$$

5.2 Appendix 2: Concept of Operations



Step Number	Step	Explanation and Justification	Timeline
1.	System calibration	<ul style="list-style-type: none"> Absolute radiometric calibration - assigns a radiometric engineering value to each measures pixel value (DN) <ul style="list-style-type: none"> Dark frame assessment Flat field calibration Photon transfer and linearity 	Late February - early March
2.	Thermal vacuum chamber testing	<ul style="list-style-type: none"> Place system into TV chamber Run TV program from -55 °C to 25 °C <ul style="list-style-type: none"> Based on predicted temp extremes for flight (Bastian 2018) Turn off chamber Remove system from chamber Check for damage (physical and calibration) 	Early-mid March
This process (calibration & TV testing) may be repeated as necessary to ensure the fidelity of the calibration and the structural integrity of the payload			
3.	System integration	<ul style="list-style-type: none"> Mount payload on gondola Connect all necessary electrical components, test to ensure they work 	Late August - early September (T=-7 days)
Between system integration and launch, HASP team will perform a final hang test (if necessary) and a mission readiness review			
4.	Launch	<ul style="list-style-type: none"> Handled entirely by HASP According to HASP Flight Operation Plan, it takes ~2 hours to reach float altitude of ~124,000 feet (~36 km) 	T=0 hours
5.	System initialization	<ul style="list-style-type: none"> When the balloon reaches float altitude (~36 km), HASP notifies payload teams. We respond with the system initialization command Alternate plan: initialize system when the flight starts and throw out unnecessary data from ascent Choice depends on how long it takes system to warm up 	T=0 hours OR T=+2 hours

6.	Data collection	<ul style="list-style-type: none"> When Raspberry Pi initializes, send signal to Pi to run data collection program <ul style="list-style-type: none"> Images will be taken once every ~60 seconds Data will be stored in a micro SD card on-board System will send data analytics to us - limited by max serial downlink (1200 bps) <ul style="list-style-type: none"> Number of image files Running total of available storage space Send every nth image back for visual analysis on the ground 	T=0 hours - T=+17.5 hours OR T=+2 hours - T=17.5 hours
7.	System termination	<ul style="list-style-type: none"> HASP operators will send a shutdown command to all payloads to prepare for descent 	T=+17.5 hours
8.	Descent	<ul style="list-style-type: none"> Balloon is released from the flight train, rapidly free falls to ~90,000 feet (~27.4 km) when the parachute begins to slow the descent 	T=+18 hours
9.	Data retrieval	<ul style="list-style-type: none"> Team provides information to HASP on how to recover, package, and ship payload <ul style="list-style-type: none"> Detailed instructions for care of sensor & computer Address for shipping HASP handles recovery, packing, and shipping 	Late September - early October
10.	Data processing	<ul style="list-style-type: none"> Visual: review images in their raw form before digital processing to make predictions <ul style="list-style-type: none"> Analyzing for measures of vegetative health and drought conditions Analytical: using davinci software, read in data files, perform atmospheric correction, and use NDVI and MSAVI2 functions to create image maps for each vegetative index Numerical: Retrieve data from NOAA and NWS databases from weather stations along the flight path 	

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