Fort Lewis College SpaceHawks

HASP 2019
Final Science Report

Written by:
Nate Todd, Jodi James, Mark Heltman, Simone Gorman, Dr. Charles Hakes

Fort Lewis College
1000 Rim Dr.
Durango, CO 81301

December 2019
Revision D

Revision Log

Revision	Description	Date
A	Conceptual Design Review	N/A
B	Preliminary Design Review	5/10/2019
C	Critical Design Review	6/21/2019
D	Analysis and Final Report	12/13/2019

Table of Contents

List of Figures

List of Tables

Abstract

Fort Lewis College students designed and built two high-altitude scientific payloads planned to be flown on two different launch platforms during the summer of 2019. The two platforms: the High Altitude Student Platform (HASP); the Colorado Space Grant Consortium DemoSat balloon. The payload subsystems included the following: a Polarization experiment (PolEx), which was the primary science experiment to measure sky polarization intensities; a Power Management System (PMS); a Temperature Management System (TMS); a Mobius high definition video camera (MoCam); a Communication System (Comms) that provided additional telemetry during the flight; and a GPS system that provided another source for down link and GPS data for the flights. For all two launches, the goal was to have the same reusable payload systems and experiment but adapted for mounting to different launch platforms. Different outer structures were used based on their respective platform, but all have the same basic inner structure: components mounted to a re-moveable sled inside a cylindrical tube, allowing the slide to be taken out, serviced, and then replaced without affecting the outer protective structure. The HASP and DemoSat launches were successful in returning data; however, the rocket was unable to launch due to scheduling concerns. Results from the various subsystems from both flights are presented and discussed.

1.0 Mission Overview

2019 Fort Lewis College (FLC) students designed and built two different payloads with the same experimental subsystems, with both of these launching to high altitudes. All two payloads carried the same payload subsystems and experiment, but with different outer structures optimized for each launch platform. Each payload had slightly different weight, size, and power requirements for each platform. Different outer structures were based on their respective platform, but all have the same basic inner structure; a slide in a cylindrical tube allowing the slide to be taken out and changed then replaced.

The first payload was launched on the High-Altitude Student Platform (HASP). The HASP platform is supported by the NASA Louisiana Space Grant Consortium (LaSPACE) and flies once a year from the Columbia Scientific Balloon Facility (CSBF) base in Fort Sumner, New Mexico. This platform is capable of carrying up to 12 student payloads to altitudes of approximately 36 km for a 15-20 hour flight duration while providing power and communications capabilities to the payloads.

The second platform was the Colorado Space Grant Consortium (COSGC) DemoSat platform. This platform carries lightweight (800 grams or less) student payloads to approximately 30 km in altitude for approximately 3 hours. Payloads are self-contained and launched from the Colorado Front Range area.

.

Level 0 requirements include:

- Build an operational payload that will deliver subsystems to a high altitude and return usable data.
- Design a payload with payload subsystems that can be used independently and that can fly on multiple platforms.
- Reuse the payload subsystems for more than one structure after the initial flight.

Level 1 requirements are categorized by subsystems:

- Polarization – Measure the polarization of incoming light as a percentage of total background lighting, and record sensor orientation and altitude. Send data to the Comms for downlink, as well as record internally.
- Mobius Camera – Record video of payload flight. Be able to alter the recording state from active to passive by command, to conserve storage space for the HASP platform.
- Temperature Management System (TMS) – Record and maintain survivable component temperatures throughout the duration of the flight, through temperature sensors and resistance heaters. Send data to the Comms for downlink.
- Power Monitoring System (PMS) – Maintain, control, and monitor power supply to all subsystems throughout the duration of the flight. Send data to the Comms for downlink, as well as receive power sourcing / re-routing commands from the Comms.
- Communications System (Comms) – Provide command/control uplink and information downlink interface to linked subsystems throughout the duration of the flight.
- GPS – Record GPS location and provide downlink for Comms throughout the duration of the flight.

2.0 Design

2.1 Polarization Experiment

Figure 1 shows the block diagram for the polarization experiment. Power is supplied to an Arduino Pro Mini which controls a photoresistor array, an altimeter, and a 9 Degree of Freedom (9DOF) board. Then the Arduino writes all the data to a micro SD card. Figure 2 shows the circuit diagram for the polarization experiment.

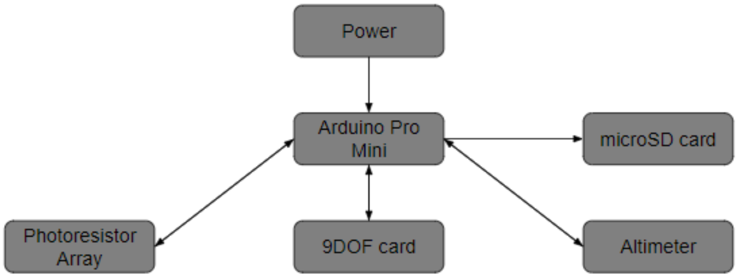

Figure 1: Polarization block diagram.

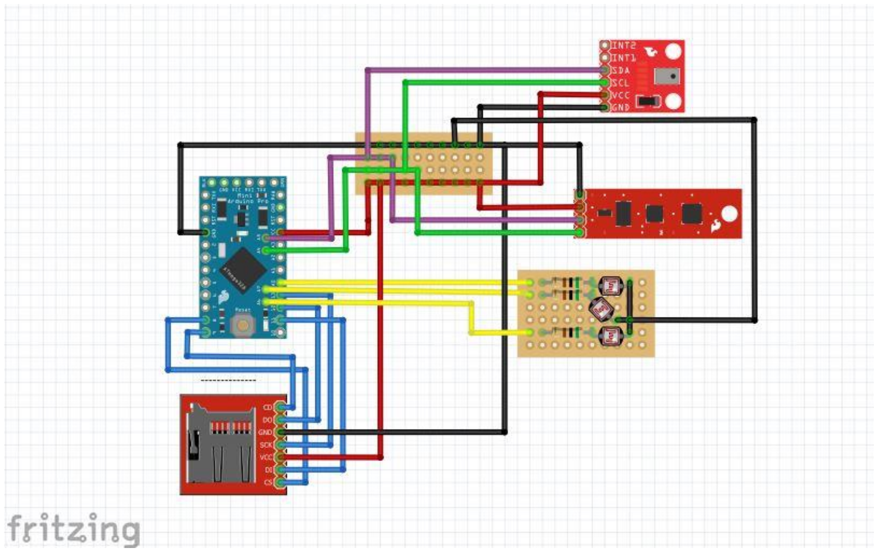

Figure 2: Polarization circuit diagram

Figure 3 shows a top-down view of the polarization experiment. The polarization photoresistor array sits inside the semi-cylindrical stand, sheltered to a narrow field of view for accurate polarization percentage reporting. This structure contains the electronics of the experiment in the most compact manner available, to include the following: a 9-degrees-of-freedom (combined accelerometer, magnetometer, and gyrometer) card for orientation awareness, a combined barometer/altimeter card for altitude tracking, a microSD board for data storage, a prototyping board for wiring, and the Arduino Pro Mini microprocessor.

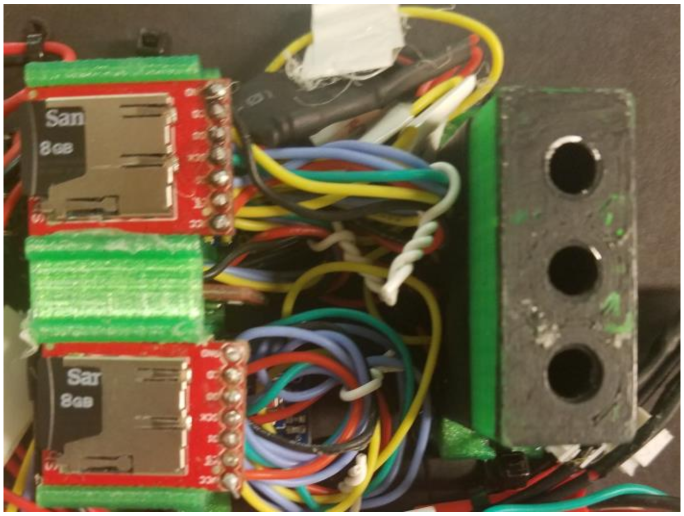

Figure 3: Actual structure and set up of polarization experiment.

2.2 Mobius Camera

The Mobius camera block diagram is shown in Figure 4. Battery power was provided to an Arduino Pro Mini which was loaded with timing for the camera. Then, the Arduino controlled an optical relay switch which turns the camera on and off as desired by the preloaded code. Figure 5 shows the wiring diagram for the Mobius camera, where the chip is an optical relay and the yellow and red LEDs are the record and power buttons on the camera.

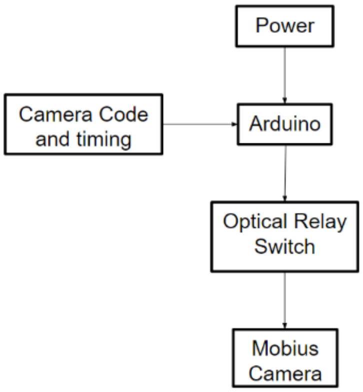

Figure 4: Mobius camera block diagram.

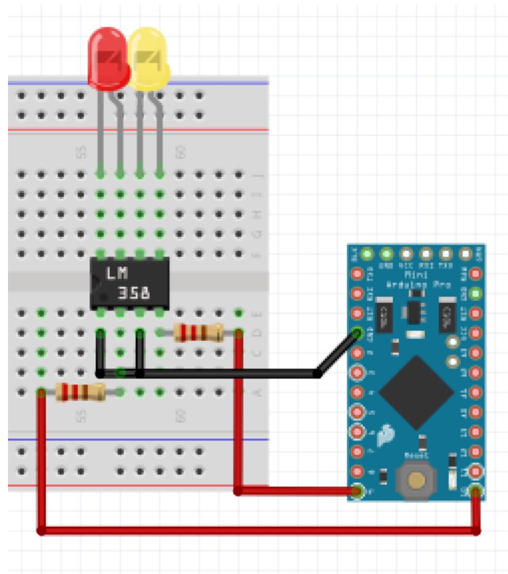

Figure 5: Mobius camera wiring diagram. The LEDs represent camera buttons.

Figure 6 shows the top down view of the mounted Mobius camera, with the far-right portion showing the Arduino Pro Mini and optical relay. The camera and board a screwed to the inside of the cylinder, allowing the lens to protrude from the outer structure after final placement for a wider field of view.

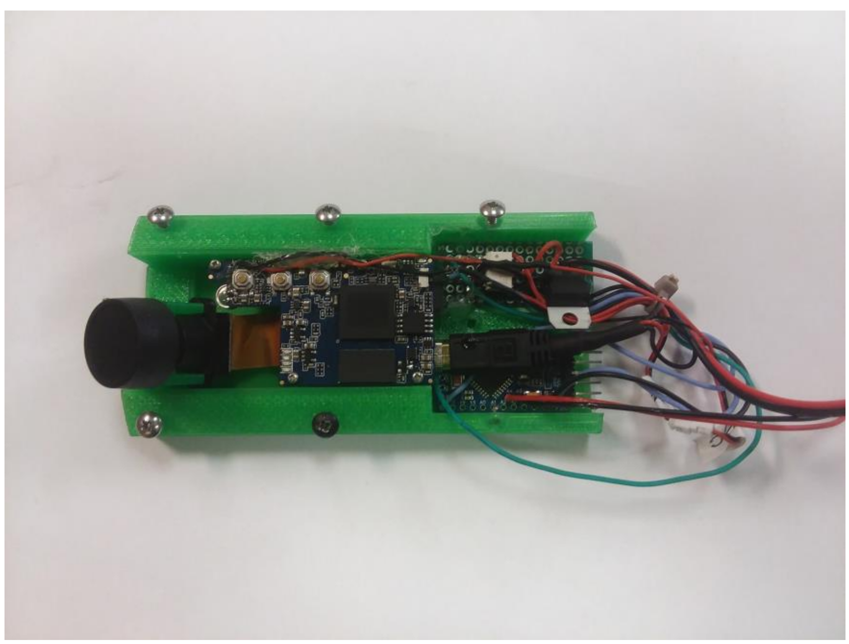

Figure 6: Top down view of Mobius camera.

2.3 Power Management System (PMS)

Figure 7 shows the block diagram for the PMS. Current sensors are placed in-line between the battery bank supply lines and the individual system draw lines (PMS, TMS, Mobius camera and polarization experiment). The Arduino Pro Mini writes data from the current sensors to a microSD card, and control an LED display to provide quick external statuses for all systems. More specifically, Figure 8 shows the circuit diagram for the PMS.

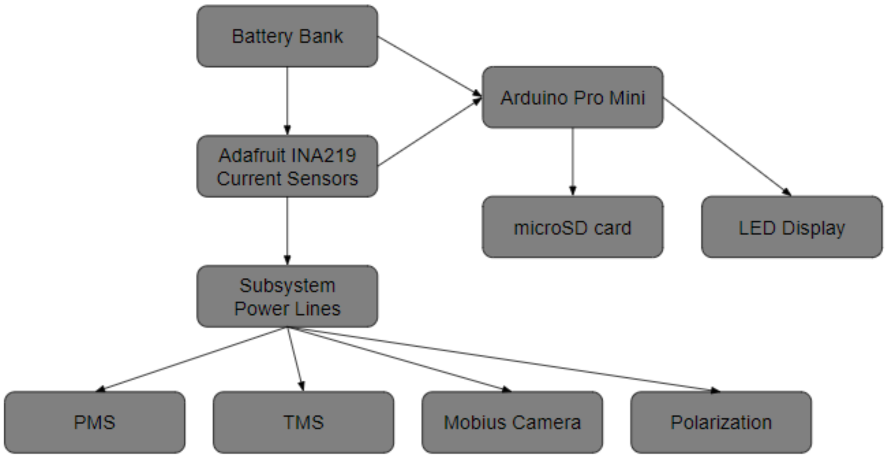

Figure 7: Power management system block diagram.

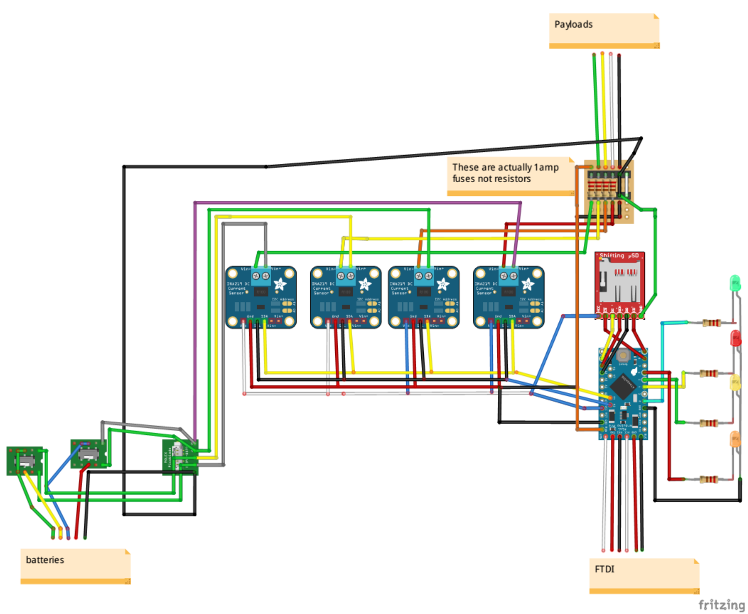

Figure 8: PMS circuit diagram

Data is written to a micro SD card, and an Arduino Pro Mini is used to monitor the current sensors. Figure 9 shows the PMS housing; it was made to fit securely into the cylindrical tube with minimal fastening.

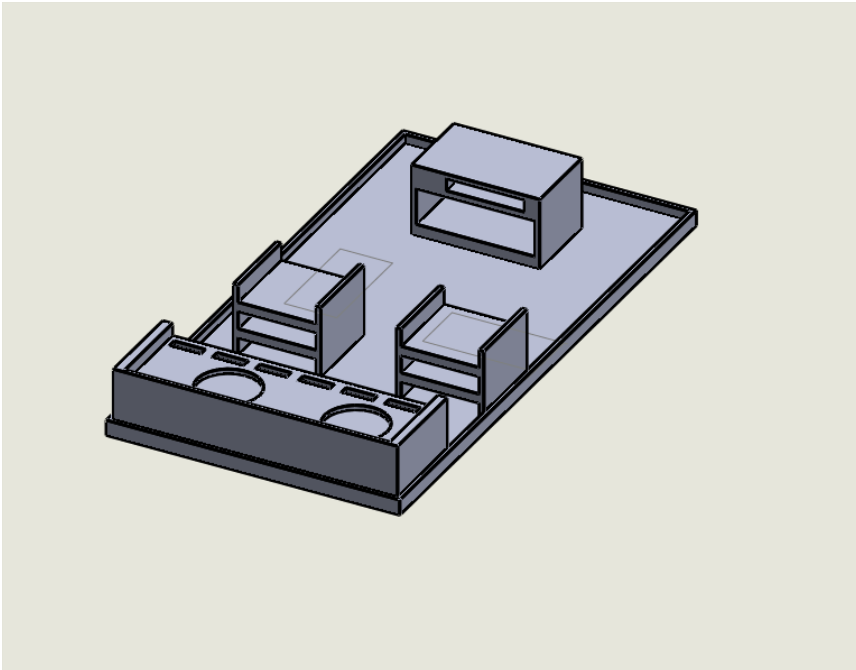

Figure 9: Drawing of PMS housing.

2.4 Thermal Management System (TMS)

Figure 10 shows the block diagram for the TMS. An Arduino Pro Mini reads temperature sensors located near all components, and turns on resistor heaters as needed when temperature drops. The heaters are powered by 7.4-volt batteries for heater effectiveness. All temperatures, heater statuses, and times are written to an internal SD card. Figure 11 shows the circuit schematic for one resistance heater and sensor. The same system would be duplicated to heat as many subsystems as needed based on the platform.

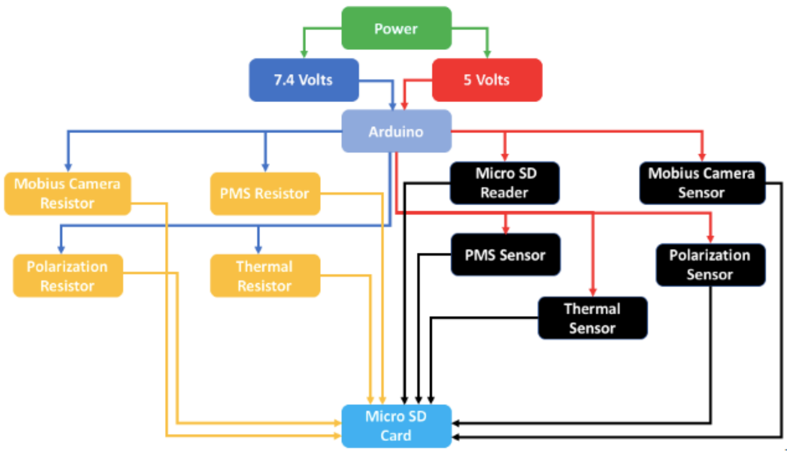

Figure 10: Thermal system block diagram.

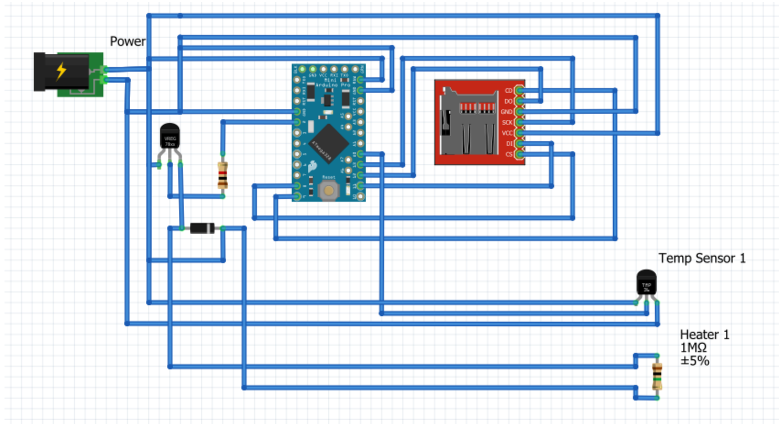

Figure 11: TMS circuit schematic for one heater and sensor.

Figure 12 shows the as-built TMS and housing. An extra 5-pin connector was added for future use but was not used in the launch. All boards are securely friction-fit to the housing and retain structural integrity during rocket and balloon launches and landings.

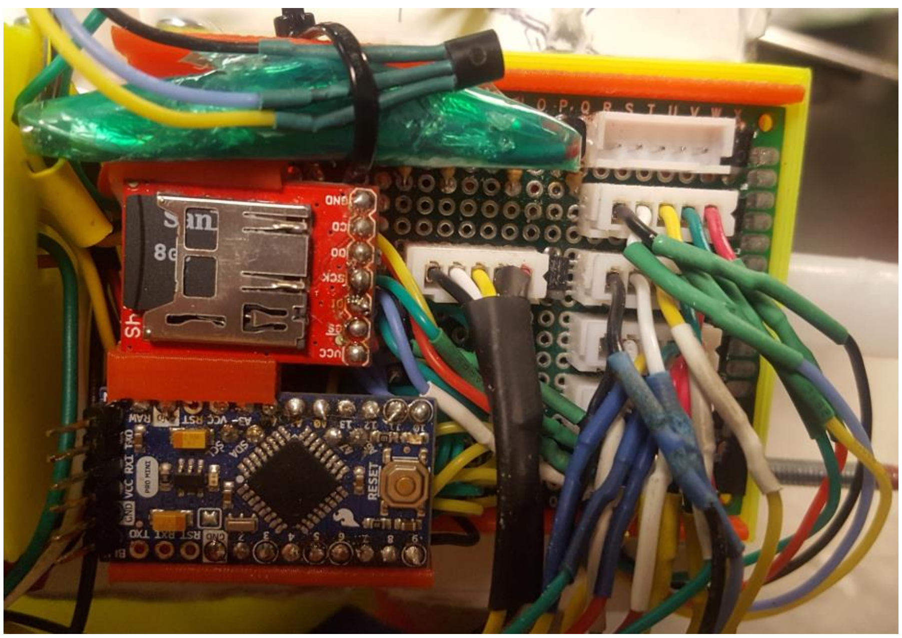

Figure 12: Actual picture of temperature management system, with extra 5-pin connector.

2.5 Communication System (Comms)

Figure 13 shows the block diagram of the Comms subsystem. The system is comprised of an Arduino Pro Mini microprocessor, which connects to three separate communication buses: an SPI bus (to communicate downlink information with the GPS); an I²C bus for intra-payload data transfer; and a UART serial bus to communicate with the HASP platform and for debugging / recoding. Also included are two logic level-shifters, to create compatibility between the various voltage levels; one is dedicated to the Comms-GPS SPI link, while the other splits the intra-payload I²C bus into 5V and 3.3V levels for interoperability.

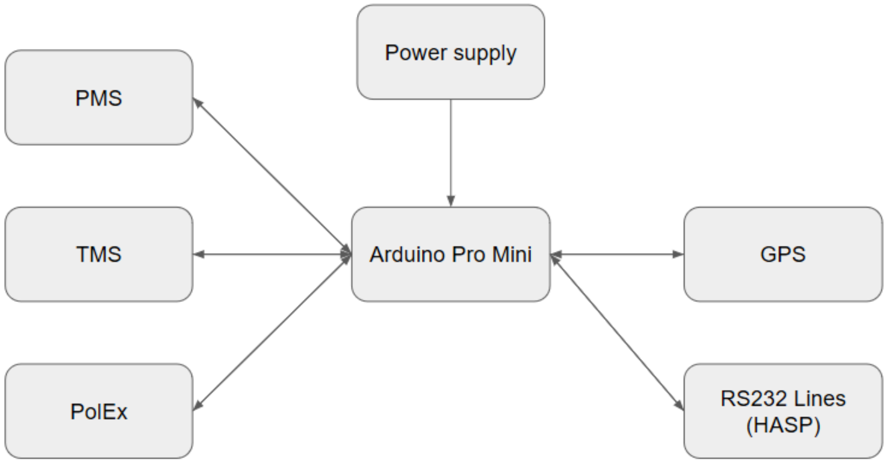

Figure 13: Communication system Block Diagram

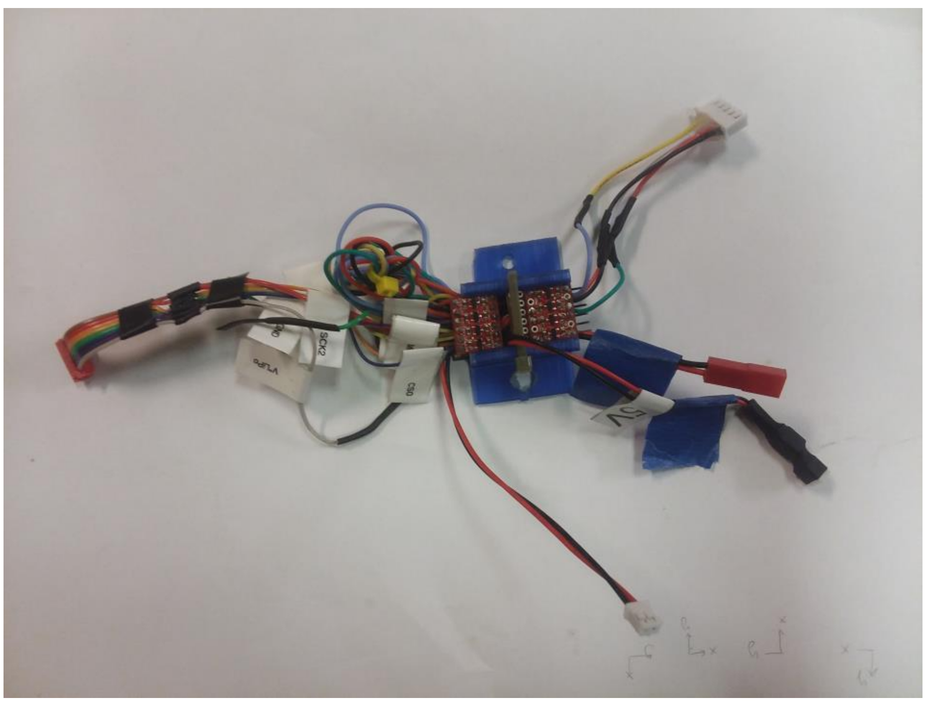

Figure 14: Comms Wiring

Figure 14 shows the completed subsystem structure, a 3D-printed PLA housing which fits compactly underneath the GPS on, and is mounted to, the payload sled.

2.6 GPS Transmitter

Figure 15 shows the Altus Metrum TeleMega flight computer used on the payload. This flight computer, developed for use in tracking high-powered rockets, has an on-board transmitter for the 435 MHz band (requiring an operating license), which broadcasts a large amount of information from the board in real-time. An undeveloped feature by the manufacturer allows the Comms subsystem to connect to the Companion connection and add more data to the downlink, allowing high-altitude, low-power downlink for the payload.

Figure 15: Altus Metrum TeleMega

2.7 Structure

2.7.1 HASP

Figure 16 shows the structure of the HASP payload. On the right is the sled made of fiberglass with all components screwed into two parallel sleds.

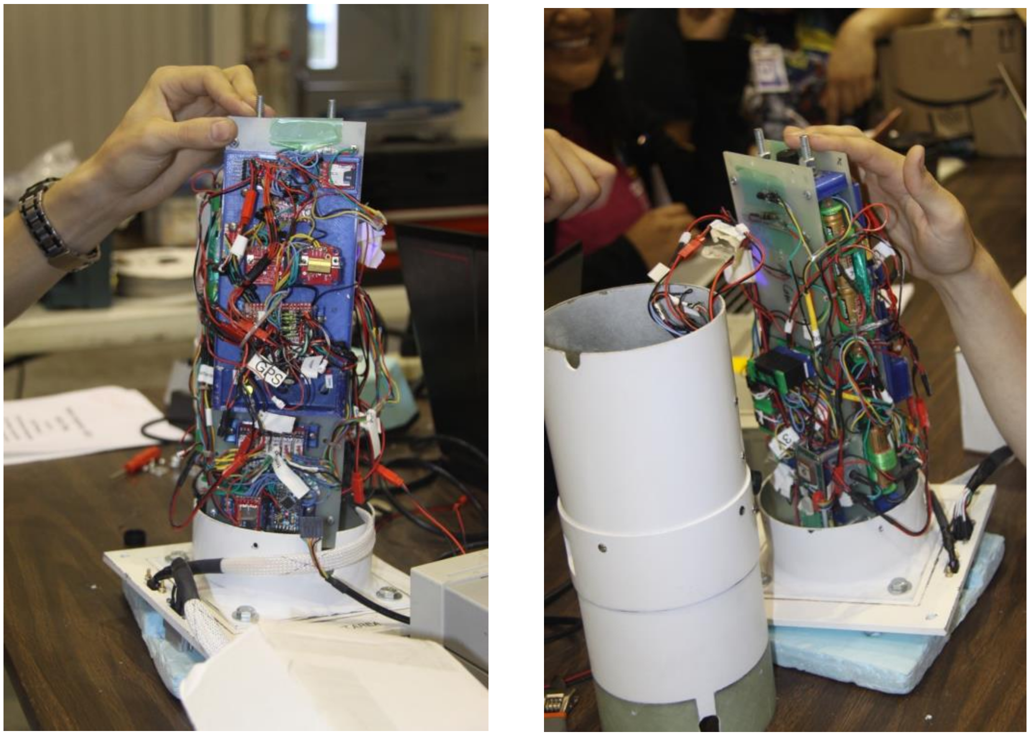

Figure 16: Inside structure side one (right), and side two (left).

Figure 17 shows the drawing of the assembled structure. The sled and outer structure is attached at a collar that is bolted to the base plate. The collar is then screwed into the outer structure to allow for easy removal and access to the payload for troubleshooting and retrieval of data for analysis.

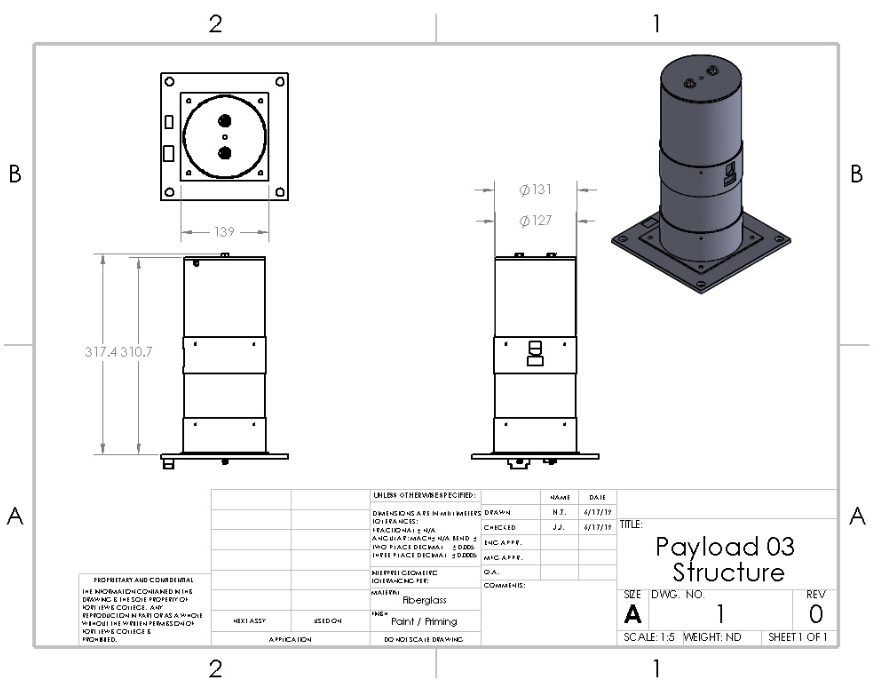

Figure 17: HASP structure drawing.

2.7.2 DemoSat

Figure 18 shows the outer structure for the DemoSat. The goal was to have it able to attach to a high-powered rocket after the DemoSat launch. The flight tube is embedded in the middle of the sled and held on via the end caps with a key ring through the tube to keep the tube from slipping through the payload.

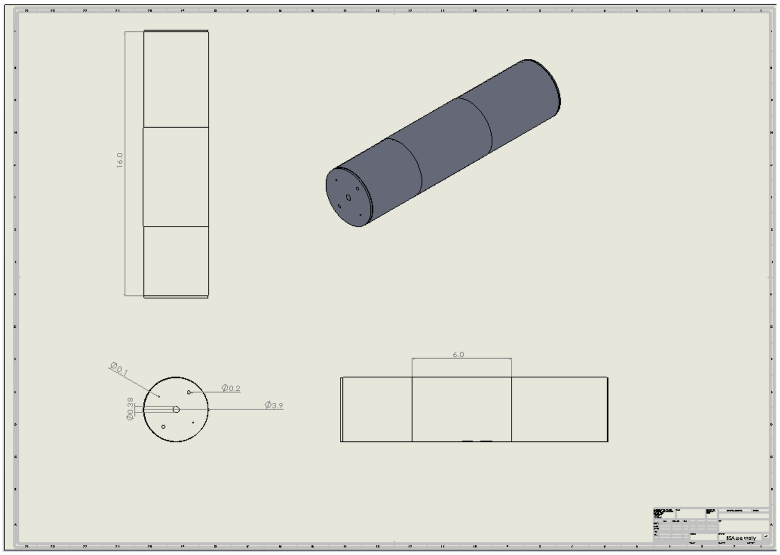

Figure 18: Outer structure drawing for DemoSat.

Figure 19 shows the completed DemoSat “sled” structure, with all internal systems mounted and readied for flight. Of note are the protruding flight tube and threaded rod for securing the “sled” within the outer cylindrical structure.

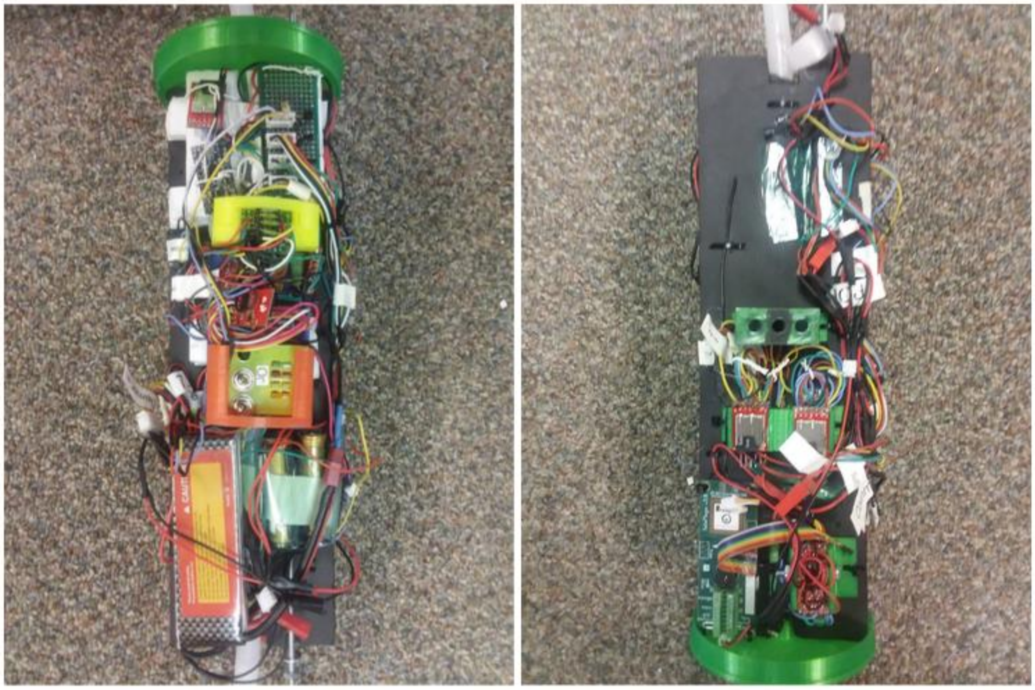

Figure 19: Inner sled structure.

3.0 Project Management

3.1 Team Composition

Each team member specialized in a specific subsystem as shown in Table 1. However, the whole team was responsible for ensuring subsystems work together, as well as that the whole payload is functional.

Table 1: Team Members and Demographics

Name	Start Date	Role	Student Status	Race	Ethnicity	Gender	Disabled
Nathaniel Todd	12/15/18	Project Manager/ Comms, MoCam	Undergrad	Caucasian	Non-Hispanic	Male	No
Jodi James	12/15/1/8	Lead Physicist/ Polex, TMS	Undergrad	Native American	Non-Hispanic	Female	No
Mark Heltman	4/30/19	Electronics Lead/ PMS	Undergrad	Caucasian	Non-Hispanic	Male	No
Simone Gorman	4/30/19	Team Member/ Structures	Undergrad	Native American	Non-Hispanic	Female	No

Brooke Hampton	4/30/19	Team Member	Undergrad	Caucasian	Non-Hispanic	Female	No
Charles Hakes, Ph.D.	12/15/18	Space Grant Affiliate	Faculty	Caucasian	Non-Hispanic	Male	No

3.2 Project Timeline

Figure 20 shows the schedule of the team where milestones are highlighted in yellow. Time was especially constricted at the end of July, with the overlap of the DemoSat launch and HASP integration. This also forced the building of the two payloads to be overlapped as well as testing. Both payloads could have been improved if building had occurred earlier and more time was allotted for troubleshooting.

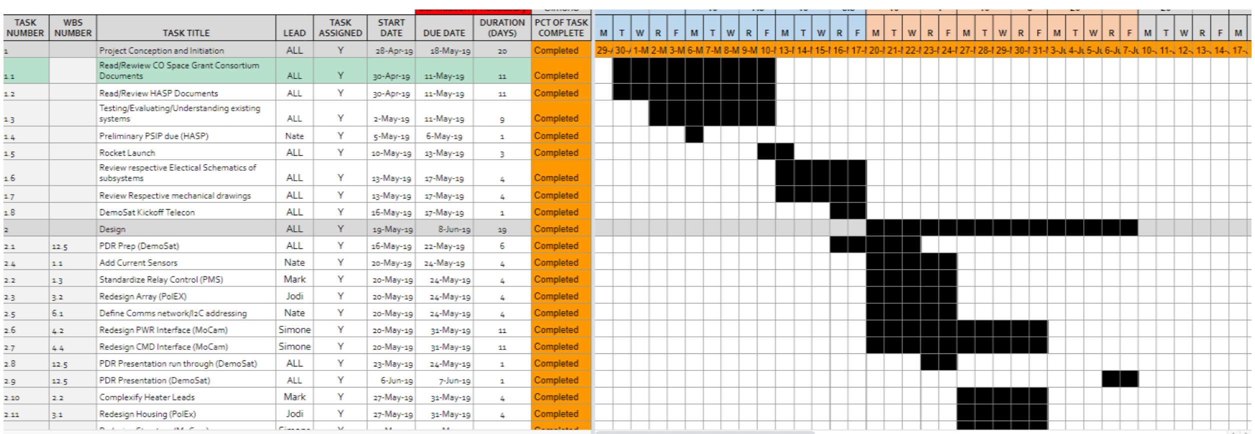

Figure 20: Gantt chart with milestones.

3.3 Mass Budget

Table 2 shows the mass budget for the payload components before they were installed on the HASP baseplate. Decals, glue, and miscellaneous hardware resulted in a slightly overweight payload.

Table 2: Mass budget

Sub-system	**Weight (g)**
Fiberglass Structure (w/system sled)	1,283
Polarization Experiment	91
Temperature Management	81
Power Management	77
Mobius Camera (battery included)	52
Altus Metrum TeleGPS	12
Misc (epoxy, paint, screws, ect.)	1124
TOTAL	**2720**

3.4 Financial Budget

Table 3 shows the financial budget for the summer's project. Large contributors to component cost came from the GPS transmitter, mobius camera, and polarization experiment components. Most large components are interchangeable between future payload launches and are intended for reuse. All housing components were 3D printed using a PLA printer at FLC, and small hardware pieces were purchased at a local hardware store.

Table 3: Approximate Expenditures for Fort Lewis College Participation in HASP

Item	Cost ($)
Travel to Palestine, TX	$2600
Hardware Total	$708.30

Student Stipends	$16,000
TOTAL	$19,308.30

4.0 Testing Plan

4.1 Functional and Structural

The team conducted an endurance test to ensure all components would work without human interaction, as well as to verify proper functionality of the programmed codes. The team also completed multiple individual component tests. Finally, the completed payload was tested for structural endurance with a drop test from a height of approximately 8 feet onto turf; post-analysis demonstrated payload survivability from ground impact.

4.2 Payload Integration Test

The team completed payload integration at a thermal / vacuum chamber on Wednesday, July 17th, at the Columbia Scientific Balloon Facility (CSBF) in Palestine, TX, to support the HASP platform. The HASP payload was put through a full vacuum (sea level to <3 mbar) and thermal (>55°C to <-60°C) cycle, ensuring all combinations of extremes over a four-hour period. After the test, it was determined that a single connector had not been properly fastened prior to the test, which led to the loss of MoCam data and intermittent Comms link for the duration of the test. The payload was immediately modified to remove the connector from the design, and the payload was returned to full functionality within 30 minutes of the test end. The team considered this an adequate test of the payload concept.

5.0 Flight Logistics

The payload was shipped to the launch site. From there, a HASP representative attached the payload to the main structure along with other HASP payloads. The launch occurred on September 5, 2019, during a school day of the first week of classes; student team members took turns monitoring the flight status and telemetry.

During flight, the HASP followed a flight path towards the Four Corners area, traversing near enough to Durango to be visible from the ground. Figure 23 displays the platform as photographed by a team member.

Figure 21: HASP as seen from Durango, CO, on 9/5/2019

At recovery, the payload was removed from the flight platform, repackaged, and shipped back to FLC. When the payload arrived back to Durango, the payload was found to have maintained structural and data integrity. All recorded data was downloaded from component micro-SD cards and stored for analysis.

6.0 Results, Analysis, and Conclusion

6.1 HASP Flight

6.1.1 Polarization System

Figure 23, Figure 23, and show the PolEx array orientation data over the flight duration on the HASP. The initial ascent stage of flight shows chaotic behavior in the pitch and roll, as expected.

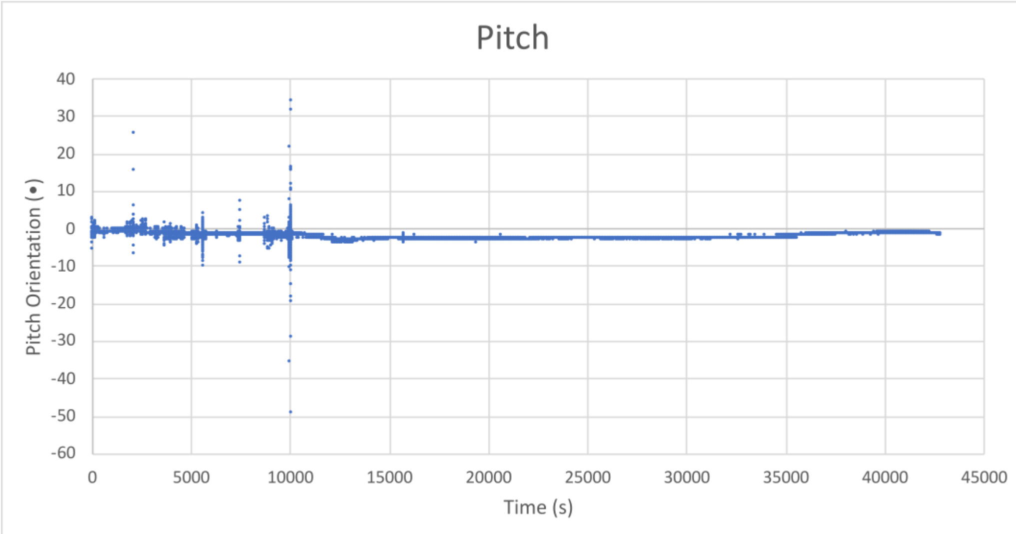

Figure 22: Array Pitch Orientation over flight duration

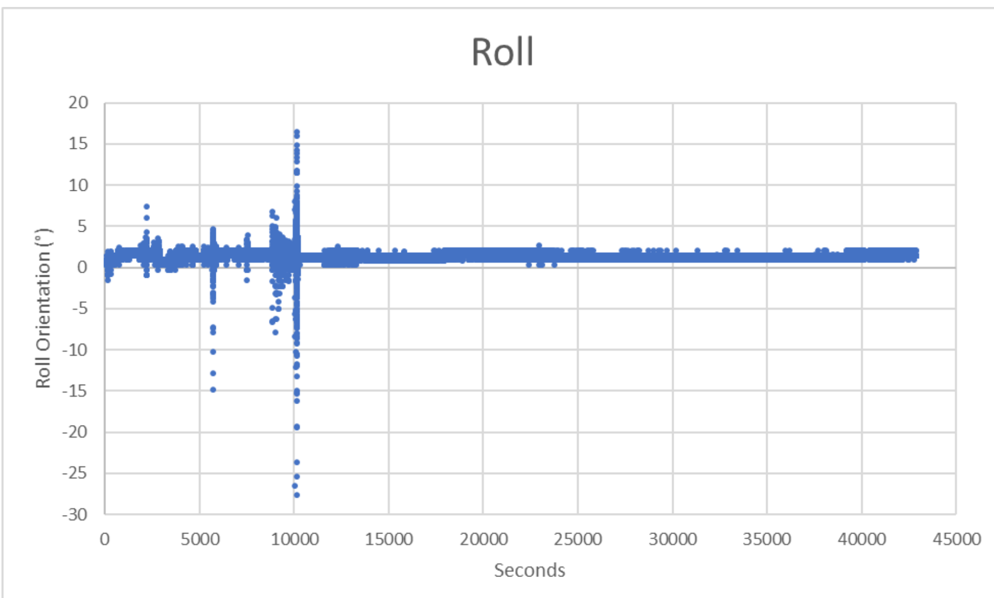

Figure 23: Array Roll Orientation over flight duration

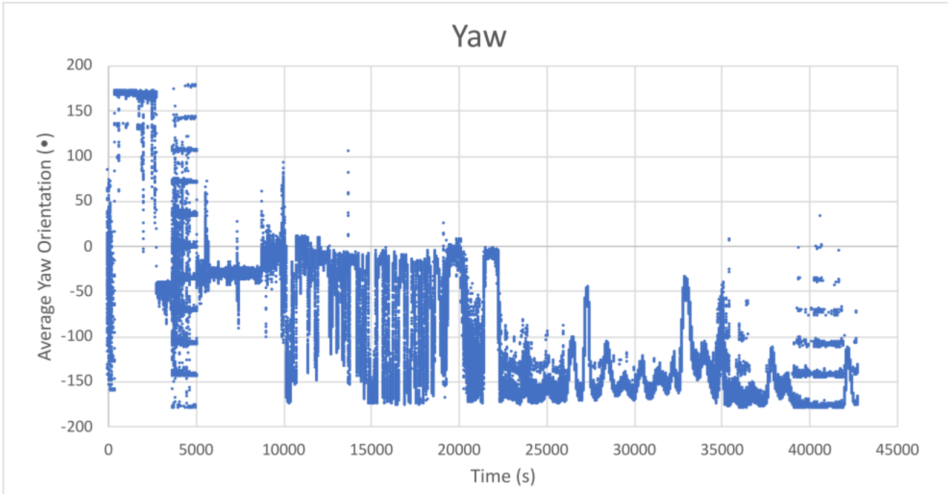

Figure 24: Array Yaw Orientation over flight duration

Next, the relative intensity of polarization through both the vertical and horizontal filters over flight duration is shown in Figure 25.

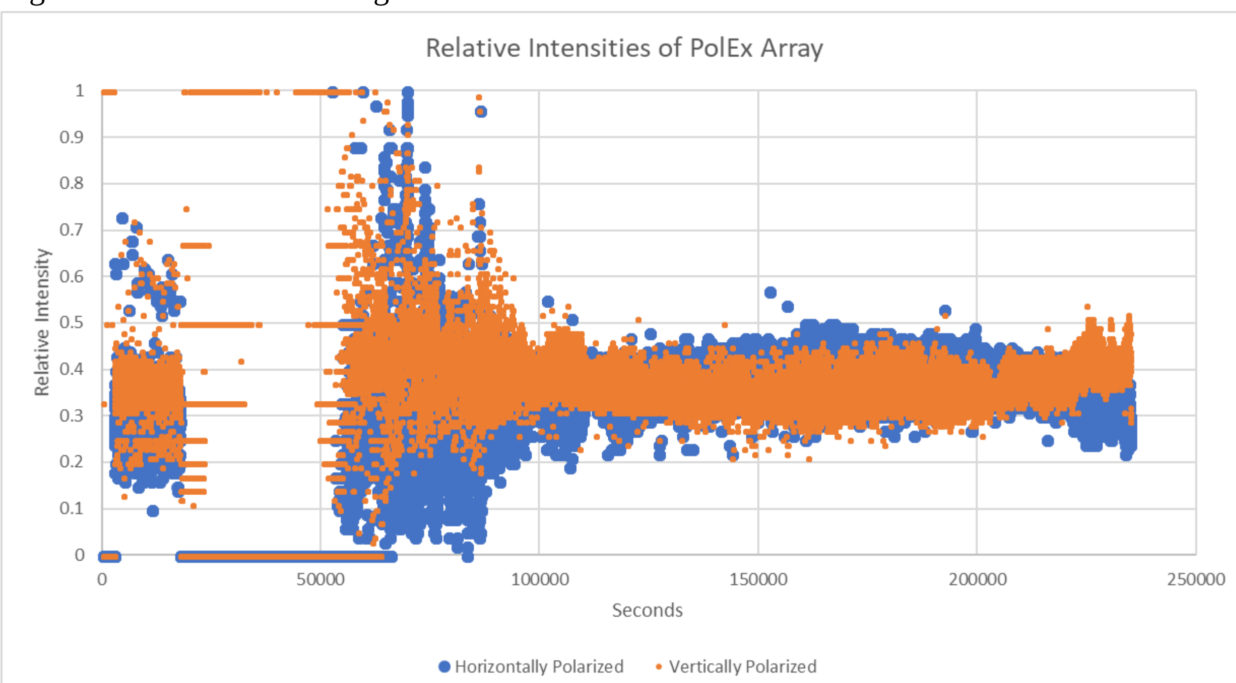

Figure 25: Relative Intensities of Polarization Filters

6.1.2 Mobius Camera System

The Mobius camera did perform on the flight. The camera recorded during launch, ascent, float, and descent. After the payload landed on the ground the camera remained on until HASP was recovered. Figure 26 shows a beautiful frame from video recorded over the Sandia mountain range near Albuquerque, NM. The city of Albuquerque can be seen in the lower right-hand side.

A sample video is found with the link : https://www.youtube.com/watch?v=7Q-YIMi8YL4&feature=youtu.be

Figure 26: HASP Float video over Albuquerque, NM

6.1.3 Thermal Management System

Figure 27 shows the temperatures over the time of the flight for all sensors. The random temperature dips and spikes come from interference with the GPS down link signal. According to the graph, the sensors were following the same path until approximately 12,500 seconds into the flight. This was early in the day when the sun was low in the sky, and also when HASP was passing through the lower temperature upper stratosphere. Upon reaching the float altitude, one side of the payload increases while the other side decreases in temperature. The Polarizer, Camera, and Empty Bay sensors decreased their temperature indicating they were facing away from the sun. While the Outside and Power Monitoring System sensors increased their temperature suggesting they were facing towards the sun. The slopes continue to increase and decrease depending on the orientation of the payload. The sensors return to the same path approximately between 37,000-42,500 seconds suggesting that late in the day solar heating is having a smaller impact on the payload.

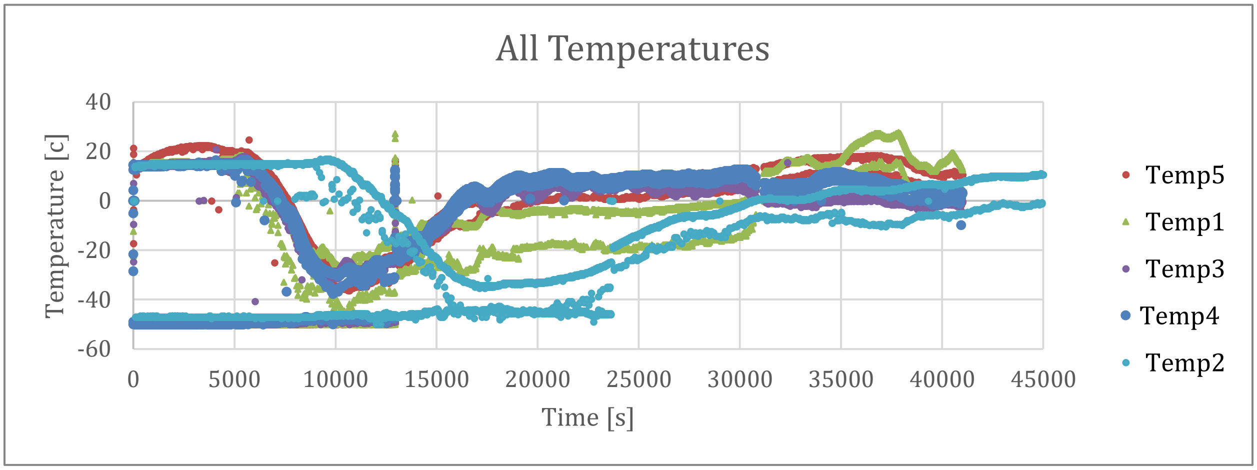

Figure 27: Temperature over time of flight for all subsystems.

6.1.4 Power Monitoring System

The power system performed with a minor failure throughout the entirety of the flight. However, its duties of monitoring system health, reporting statuses through the downlink, and processing uplinked commands where not affected. The failure was that the system did not record any data to the internal SD card. All data that is shown below was transmitted via the downlink. **Error! Reference source not found.** shows that the when the command to turn off the GPS was sent, the GPS's current draw went down to zero (~32000 seconds). Figure 30 shows the current draw for the Mobius Camera; the oscillation shows how the Arduino was able to turn on and off the camera every 10 seconds. Figure 30 is a zoomed in figure of the Mobius current draw. Figure 31Figure 31: Current Draw for all Systems shows the recorded current draw for all systems on the payload; on average, the maximum current was only 200 ma.

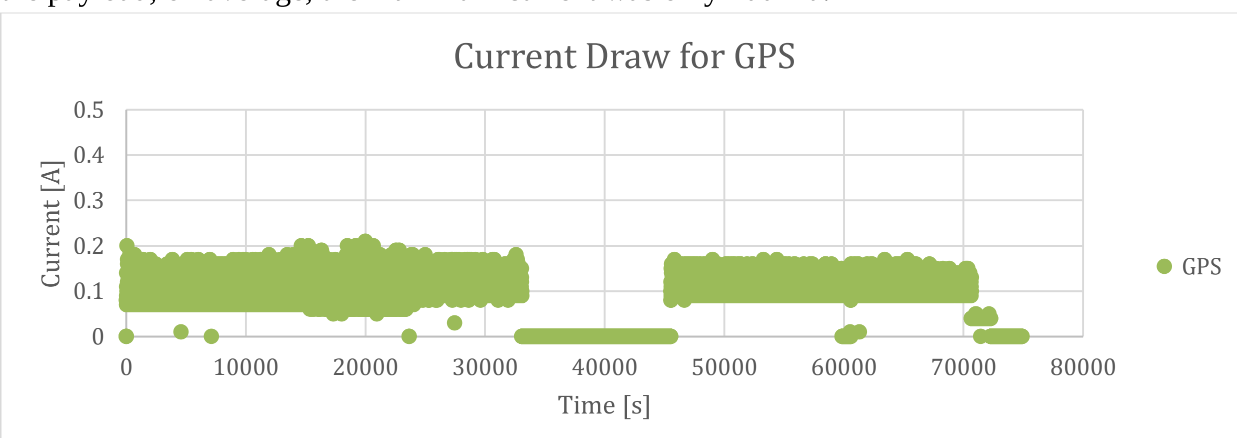

Figure 28: Current Draw for GPS

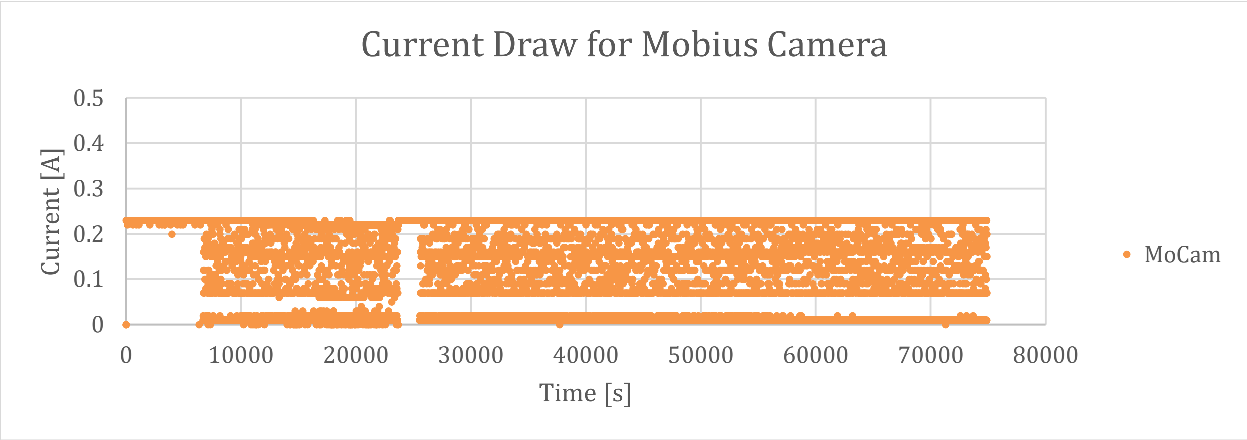

Figure 29: Current Draw for Communication System

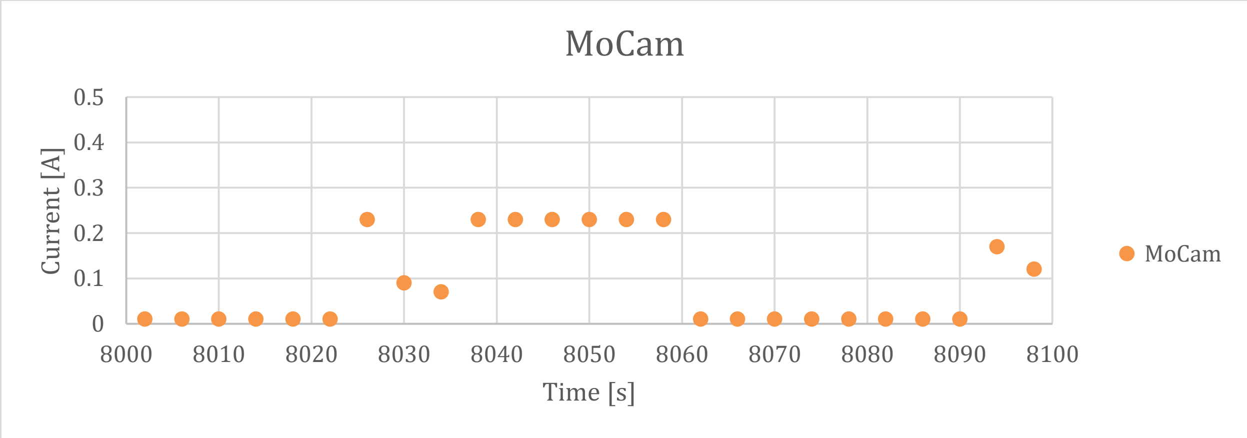

Figure 30: Zoomed in Mobius Camera current draw.

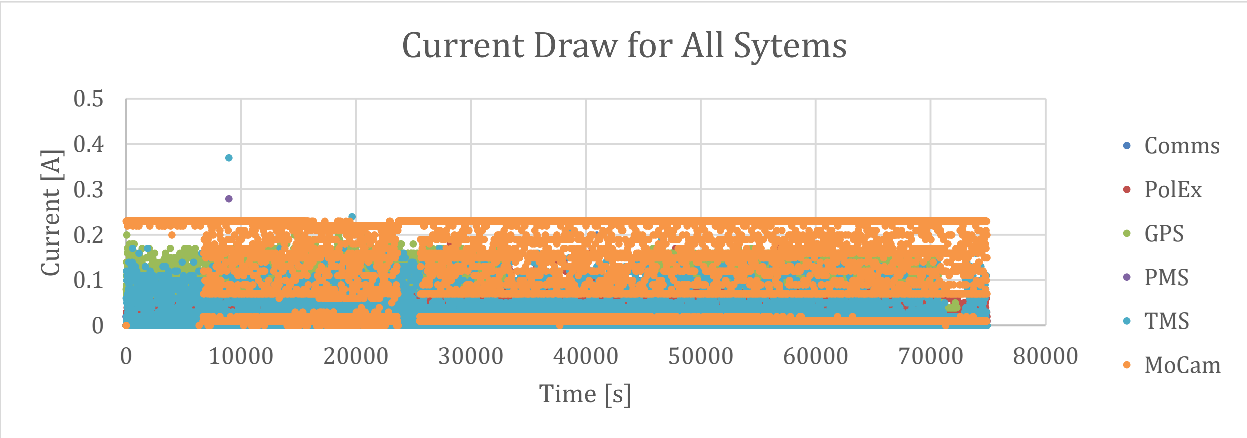

Figure 31: Current Draw for all Systems

6.1.5 GPS

Figure 32 shows the flight path of HASP. The maximum altitude was approximately 36,000 meters, and the payload flew from Fort Sumner, NM in a northwest direction to the Four Corners, in the south eastern portion of Utah.

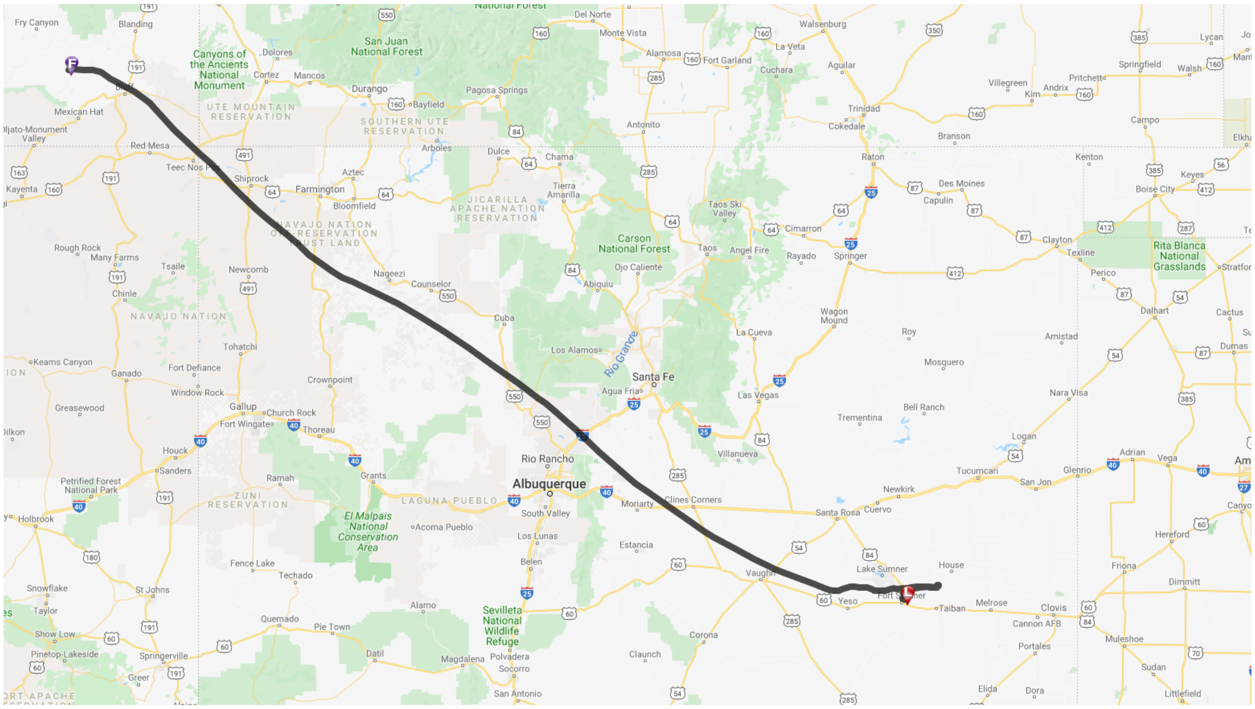

Figure 32: GPS plot of HASP flight path shown in Google Earth.

6.2 DemoSat

The Team SkyHawk payloads flew on two separate Colorado Space Grant Consortium DemoSat flights launched from eastern Colorado by the Edge of Space Sciences.

6.2.1 Polarization System

Polarization system recoded during the entirety of the flight. The IMU did not record data but it was only intermittently. Figure 33 shows the pitch data from the DemoSat flight. This is a sample of the data that was recorded.

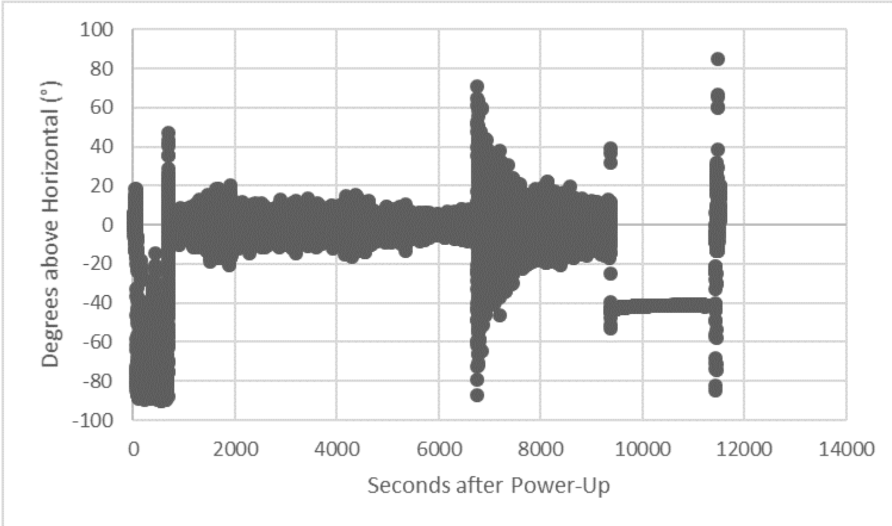

Figure 33: PolEx IMU pitch data.

6.2.2 Mobius Camera System

The camera recorded video during the entire flight until the batter voltage was too low to continue recoding. The edited video is at https://www.youtube.com/watch?v=caEF2VV0z6E

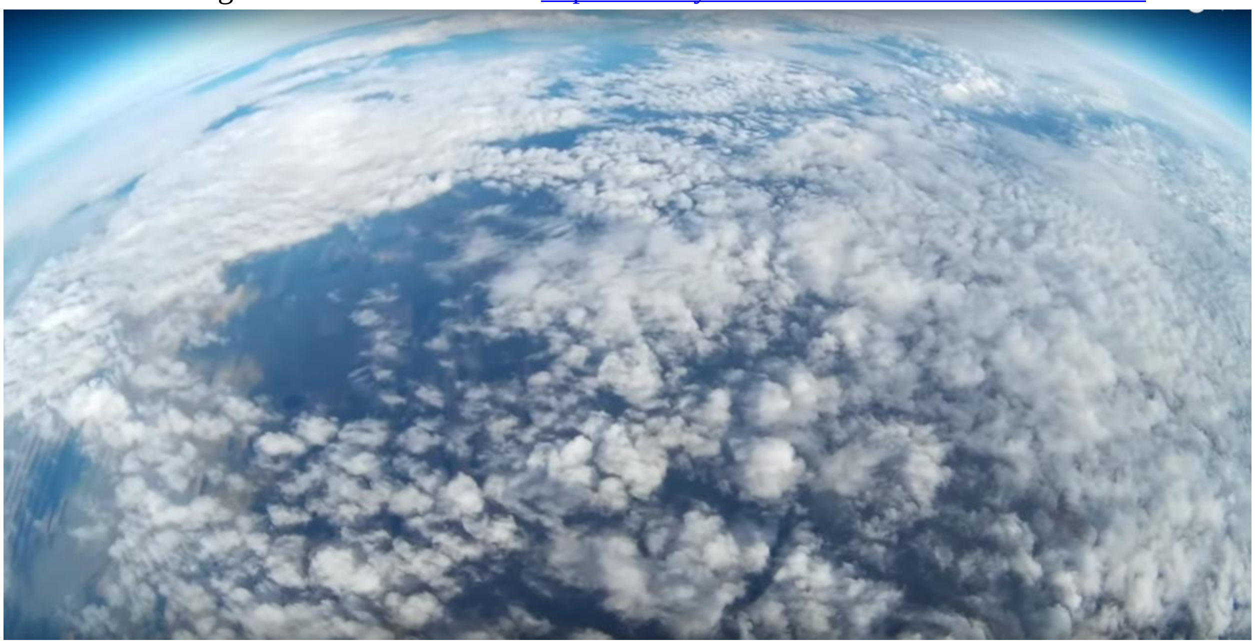

Figure 34: Single Frame from DemoSat flight video

6.2.3 Thermal Management System

Figure 35 shows all of the raw data from the temperatures of all components on the payload. The temperature dropped and then rose on the way up and the dropped quickly then warmed up as the payload descended, and the air temperature warmed up throughout the flight. The outside air temperature was the coldest, proving that the insulation added to the batteries helped keep them warm enough to function within operating range. Another indication for successful operation of the Thermal system is that all components have similar temperature paths while in flight. From the placement of the components, the Mobius camera was located on the side of the payload with an opening to the outside, which explains the second lowest dip of the graph between 1000-6000 seconds. The Mobius camera is the second coldest temperature between that time range. The other components were placed inside center of the payload which explains the three slopes to be very close to each other. From 8000-16,500 second the components temperature slopes have become like that of a logarithmic curve, suggesting the payload has returned to Earth and was waiting to be found.

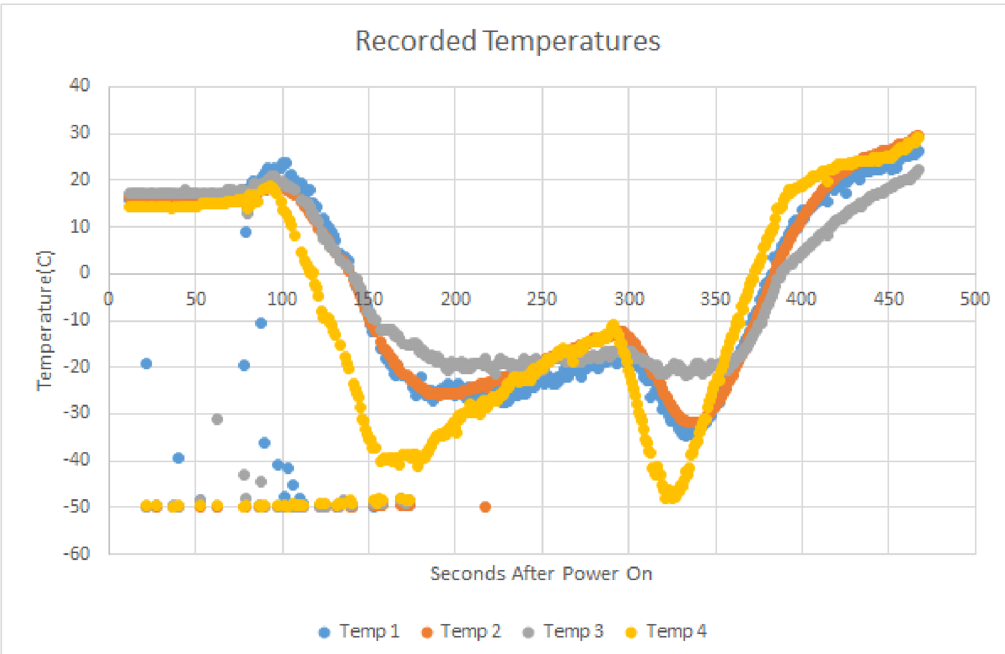

Figure 35: All temperatures.

6.2.4 Power Monitoring System

Figure 36 shows the TMS current data for the flight. Most of the current was used at the beginning -- this could have been because temperature dropped quickly then warmed up as the payload descended, and the air temperature warmed up throughout the flight.

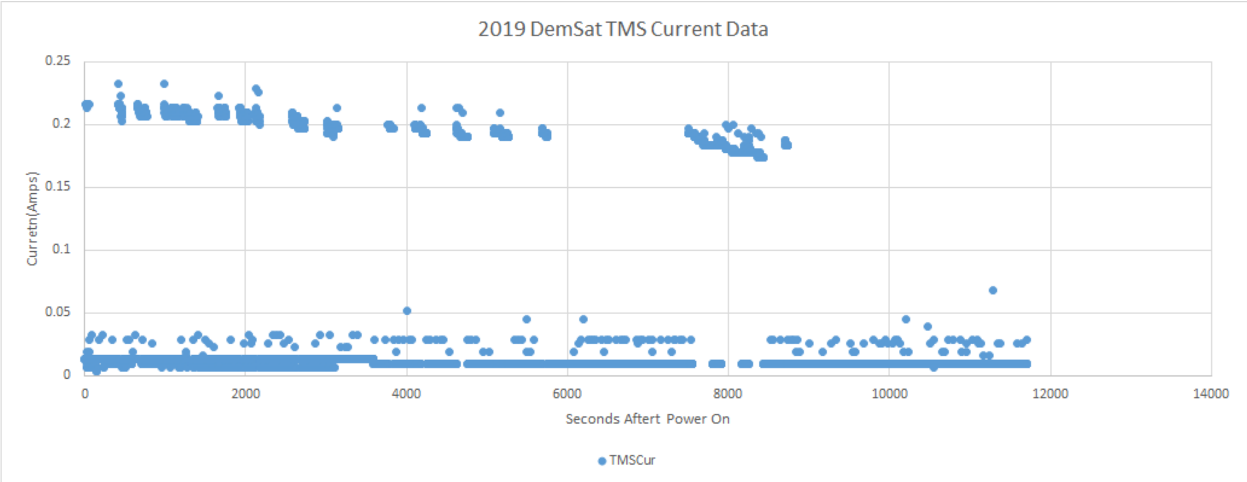

Figure 36: TMS current data.

Figure 37 shows the polarization and GPS current data throughout the flight. Both subsystems had constant current draws because they were on for the entire flight.

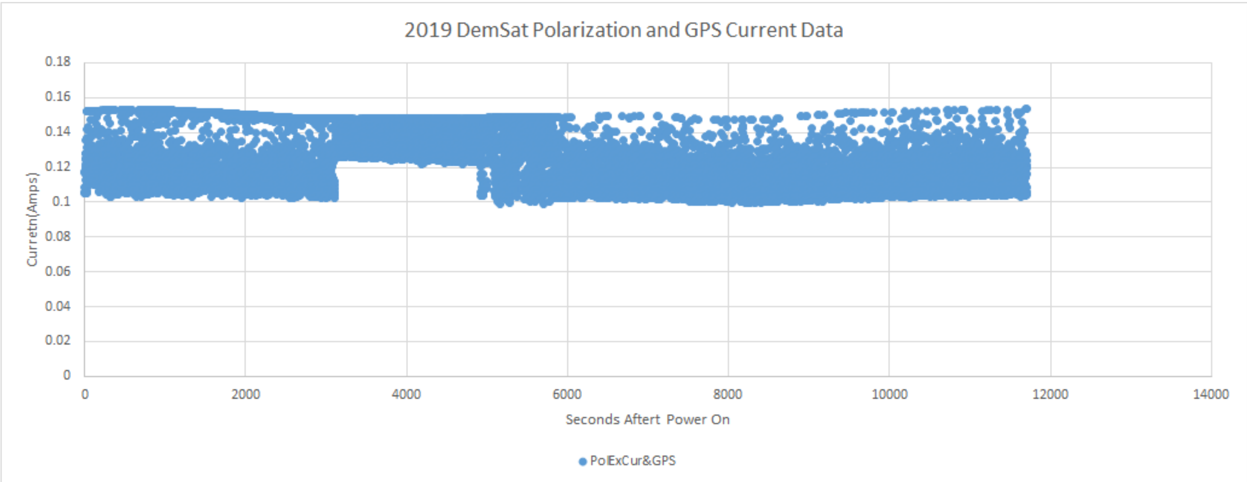

Figure 37: Polarization and GPS current draw.

The Power Management System (PMS) data is shown in Figure 38 – it stayed very constant with some drop off in the end. This could have been because the Mobius camera stopped working early, and the TMS had less current draw as temperatures increased throughout flight.

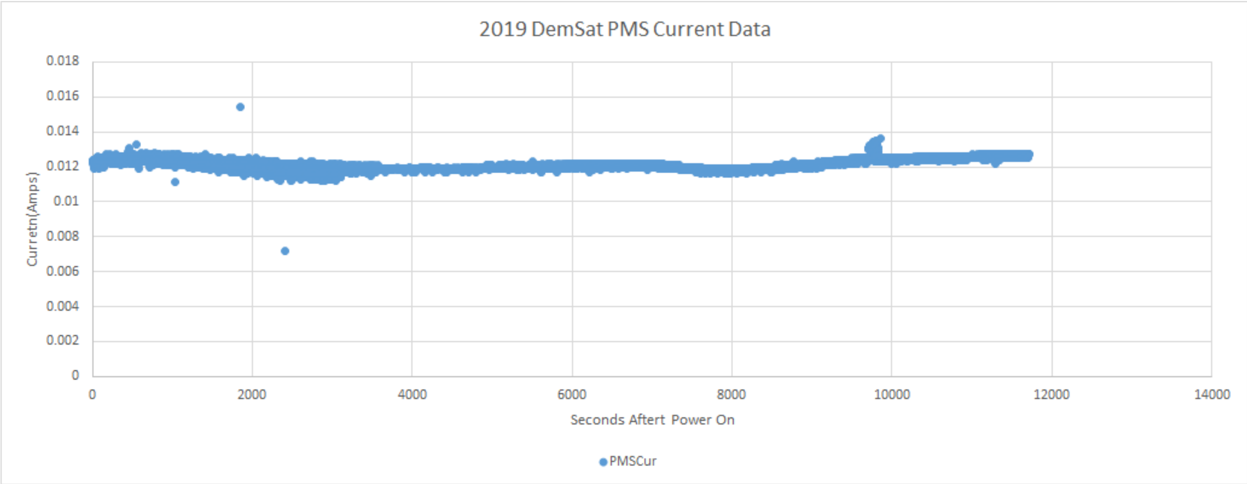

Figure 38: PMS current data.

6.2.5 GPS

Figure 39 shows the GPS data from the flight, and more specifically the flight ground track. The maximum altitude that was recorded was over 14,000 meters. There were strong mid-level winds, so the flight path made an interesting ground pattern. The GPS stopped recording due low battery voltage.

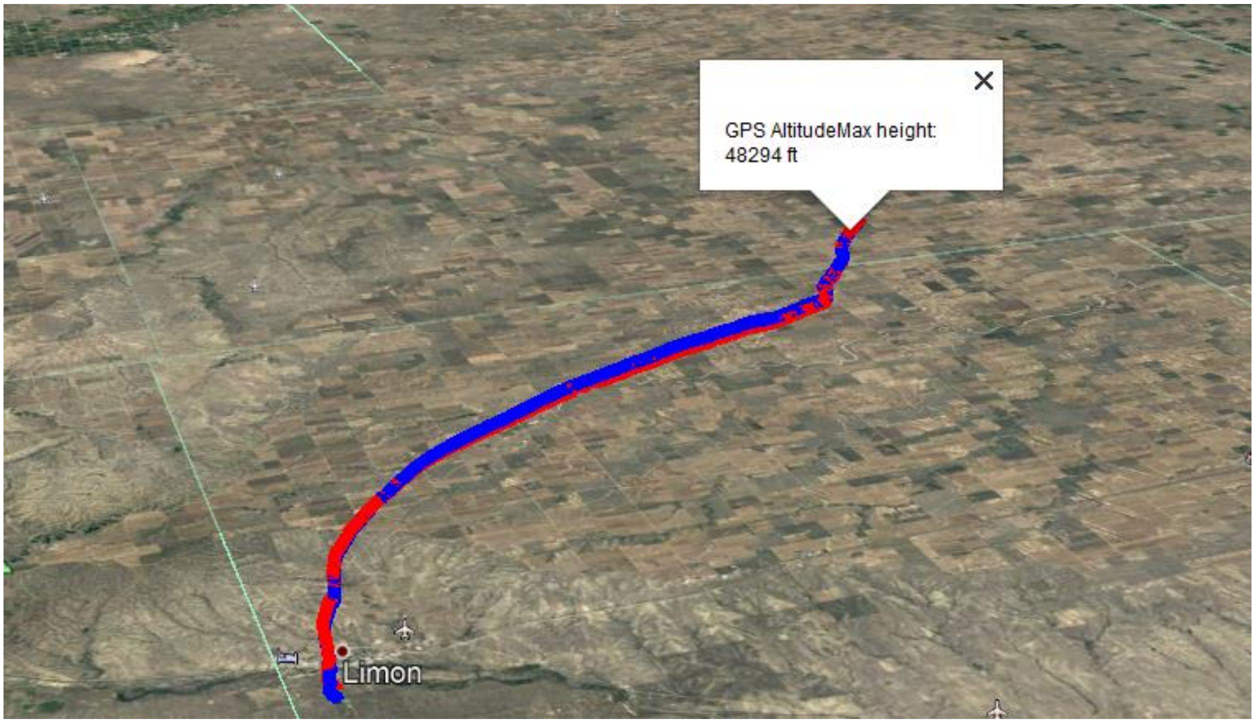

Figure 39: GPS track as shown in Google Earth

6.3 Failure Summary

The PMS did not record data during the HASP flight. This could have been because the SD card came loose during transport to the HASP launch facility, or the SD was not properly seated when it was installed. Post flight inspection of the PMS system did not uncover any loose or broken wires. For future flights, a new way of storing data without the need for a physically removeable system might be needed, or else a way to positively reinforce the SD card in its holder.

7.0 Conclusions and Lessons Learned

The team learned the difference between, and key interaction of, designing a payload and building a payload. This also comes with troubleshooting when systems do not work. Most troubleshooting could be solved by changing parts of the payload and then understanding how one change could impact the whole payload. More time building, testing, and troubleshooting would be ideal if this could be done again. However, for a completely new team who has never launched a balloon or rocket, problems were minimal and only a few changes were made to the make the payload fully functional. Figure 40 shows the team holding the payload after a successful integration activity at the Columbia Scientific Balloon Facility in Palestine, TX.

All Level 0 requirements were successfully achieved. These include:

- Build an operational payload that will deliver subsystems to a high altitude and return usable data. This was achieved.
- Design a payload with payload subsystems that can be used independently and that can fly on multiple platforms. This was achieved.
- Reuse the payload subsystems for more than one structure after the initial flight. This was achieved.

All Level 1 requirements were achieved, and discussed by subsystems:

- Polarization – Measure the polarization of incoming light as a percentage of total background lighting, and record sensor orientation and altitude. Send data to the Comms for downlink, as well as record internally. Quantify relation to altitude, and angle from sun.
    - .
- Mobius Camera – Record video of payload flight. Be able to alter the recording state from active to passive by command, to conserve storage space for the HASP platform.
    - This was a complete success on HASP; over 93 GB of high-definition video were recorded during flight. The cycling system worked flawlesly to allow intermittent record of float and full record of launch, ascent, descent, and landing.

- Temperature Management System (TMS) – Record and maintain survivable component temperatures throughout the duration of the flight, through temperature sensors and resistance heaters. Send data to the Comms for downlink.
    - This was a success. Internal RF emission from the GPS caused mild noise in the solid-state temperature sensors; however, the TMS continued to perform well despite this.
- Power Monitoring System (PMS) – Maintain, control, and monitor power supply to all subsystems throughout the duration of the flight. Send data to the Comms for downlink, as well as receive power sourcing / re-routing commands from the Comms.
    - This was mostly successful. While a full internal record was not kept, the system still performed as designed to maintain power supplies and record payload health, downlinking the appropriate data to the Comms.
- Communications System (Comms) – Provide command/control uplink and information downlink interface to linked subsystems throughout the duration of the flight.
    - This was successful. The Comms demonstrated complete confidence in controlling independent processors while maintaining two-way communications.
- GPS – Record GPS location and provide downlink for Comms throughout the duration of the flight.
    - This was successful. The GPS performed well in maintaining communications; future teams could continue to investigate its potential for downlink capability.

Figure 40: Team after a successful integration.

8.0 Message to Next Year

The biggest thing that should be stressed to next year is to leave more time for testing and troubleshooting. With building two payloads, more time should be left for troubleshooting and testing with each. Another lesson is to make all subsystems slightly smaller than what is measured -- the payload is tightly packed and this could have caused some wires to come loose when loading the sled into the main structure. Last, the payload came in slightly overweight, this could be because of glue and wires. If possible, use as little adhesives as possible and send circuits to get etched for a smaller and lighter weight payload.