Colorado Space Grant Consortium

DEMOSAT
DESIGN DOCUMENT

SpaceHawks

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8/9/2019

Revision D

Revision Log

Revision	Description	Date
A	Conceptual Design Review	N/A
B	Preliminary Design Review	5/28/2019
C	Critical Design Review	6/29/2019
D	Analysis and Final Report	7/9/2019

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1.0 Mission Overview

1.1 General

The 2019 Fort Lewis College SpaceHawks team focused on three intertwined objectives: develop a high-altitude scientific research payload; engineer the same payload to operate on multiple different launch platforms, and exercise design choices to allow total payload reusability with minimal maintenance. The payload centered around a Rayleigh Polarization experiment, and also included the necessary support subsystems and a camera. This payload used the previous year's payload as a design template, making improvements and design changes as the payload evolved. Two major changes to the overall design was an upgrade to the GPS subsystem, and the addition of a Communications subsystem.

Two different launch platforms were used for the same payload. For both platforms, the challenge was to keep the payload subsystems as identical as possible, making only the necessary power, communications, and structural changes necessary to each platform. The outer structure differed based on the platform, but both had the same basic inner structure; a flat "sled" inside a cylindrical tube, with all payload subsystems except the camera mounted to this sled. This allowed the sled to be taken out of the outer structure for easy servicing, then replaced.

The first platform used was the Colorado Space Grant Consortium (COSGC) DemoSat platform. DemoSat is a lightweight balloon platform that flies student designed/built experiments and electronics to approximately 30 kilometers in altitude. The DemoSat platform accommodates a maximum payload weight of 1 kg and does not provide communications or power to the payload. DemoSat flies three times per year and launches from the Denver, Colorado vicinity.

The second was the High Altitude Student Platform (HASP), designed to carry up to twelve student payloads for 15-20 hours up to an altitude of 36 kilometers. The twelve payloads are designed and built by students from various institutions and can weigh as much as 3 kg while being provided power and communications. The HASP platform is supported by the Louisiana Space Consortium (LaSPACE) and flies once a year from the Ft Sumner Scientific Balloon Facility base in Fort Sumner, New Mexico.

The majority of subsystem hardware was designed to accommodate both platforms and was 3D printed in-house using Poly-Lactic Acid filament. The primary alteration between the two platforms was a more lightweight sled and cylinder for DemoSat, as well as including batteries with the DemoSat payload. The subsystem for power management also had additional internal electronics, due to the command/control capability of the launch platform. All other payload subsystems were invariant.

1.2 Polarization Experiment

The Polarization Experiment (PolEx) is designed to measure the polarization pattern of the sunlit-sky and to compare this pattern as a function of altitude over the same area. The Rayleigh scattering of sunlight in the atmosphere (responsible for the blue color of the sky) is polarized to a degree, which increases to a maximum at a 90° angle to the incoming light source. The PolEx aims to determine a functional relationship between this relative polarity and altitude at the launch location. This data can have several uses; it is hypothesized that heavier pollutant molecules in the upper atmosphere will reduce the relative intensity of this polarization at more polluted launch locations than others.

The experiment array uses three photosensors, two of which are covered by opposing polarized lens (one lens is orthogonal to the other) while the third is uncovered. These sensors are placed at the base of an aiming case, restricting the view factor to approximately 0.01 of the spherical coordinate system. The uncovered sensor is used to determine a baseline intensity reading, while the other two are used to determine the relative polarity against their orientation. Using an inertial measurement unit (IMU) and a barometer, the experiment is able to track the relative polarities at any known pitch, roll, heading, and altitude over the length of the flight. Post-flight processing allows quantifying the angle between the array and the sun, allowing a comparison between this angle and relative polarity.

The new 2019 design of the PolEx system uses a Serial Peripheral Interface (SPI) communication protocol among the Arduino Pro Mini microprocessor, the IMU, and the barometer, as well as microSD cardboard for data storage. Due to the requirement of downlinking and uplinking data for the HASP launch platform, the PolEx also uses a inter-integrated circuit (I^2C) bus to communicate with the Comms system. Finally, because the higher-precision IMU used this year, paired with a microSD board, had a larger dynamic memory requirement than previous iterations of the experiment, the IMU was connected to a separate Arduino board and linked to the rest of the experiment with the I^2C bus.

2.0 Requirements Flow Down

Level 0 requirements included: Build an operational payload that will deliver subsystems to a high altitude and return usable data; Design the same payload on multiple platforms and Reuse the payloads for high powered rocket launches after the initial flight.

Level 1 requirements were categorized by subsystems:

- Mobius Camera (MoCam) - 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.

- Polarization Experiment (PolEx) - 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.

- Temperature 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 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 (HASP).

- Communications System (Comms) - Provide command/control uplink (HASP) and information downlink (Both) 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.

3.0 Design

3.1 Polarization Experiment (PolEx)

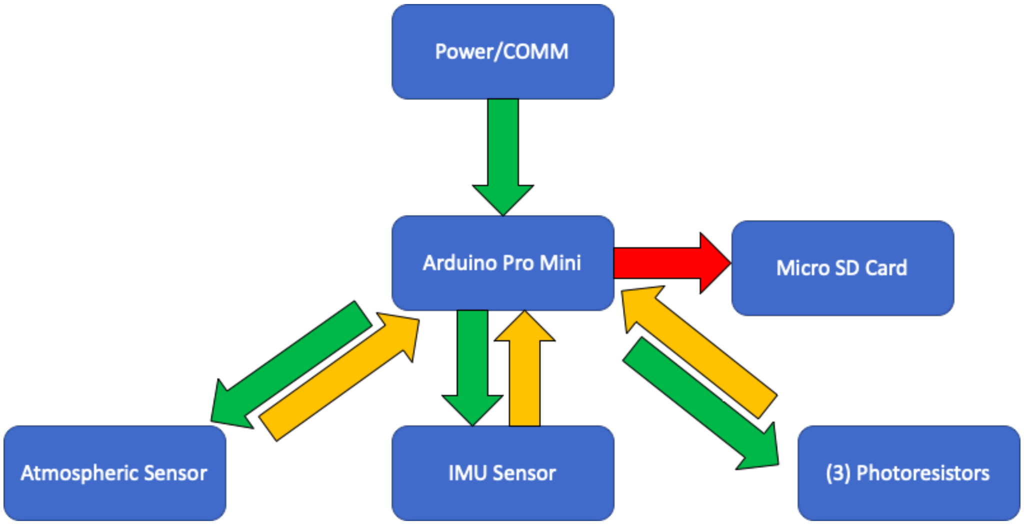

Figure 1: Polarization experiment block diagram.

Figure 1 shows the block diagram for the PolEx. The Arduinos simply read the data streams from the IMU, barometer, and photosensor array, and write them to an internal microSD card. Additionally, the Arduino's respond to data requests from the Comms subsystem and listen for uplinked commands (HASP).

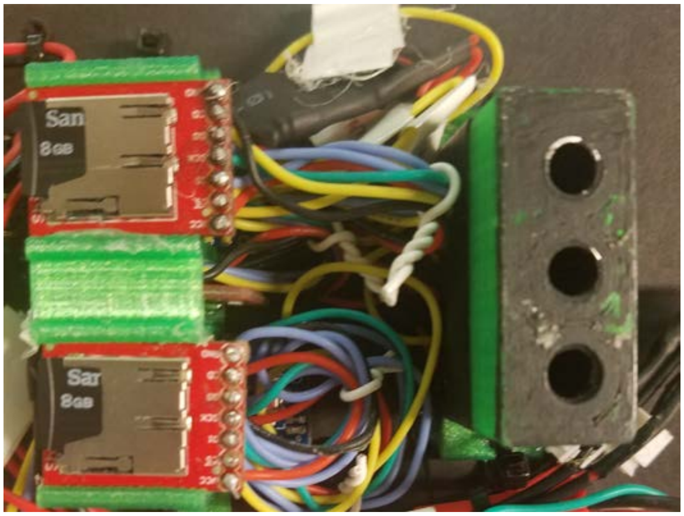

Figure 2: Actual structure and set up of the polarization experiment.

Figure 2 shows a top-down view of the PolEx. The polarity-filtered photoresistor array is mounted inside the rectangular stand, sheltered to a narrow field of view for accurate polarization percentage reporting. This stand mounts onto the sled, along with the electronics housing. This housing 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) IMU card for orientation awareness, a combined barometer/altimeter card for altitude tracking, two microSD boards for data storage, a prototyping board for wiring, and two Arduino Pro Mini microprocessors.

3.2 Mobius Camera

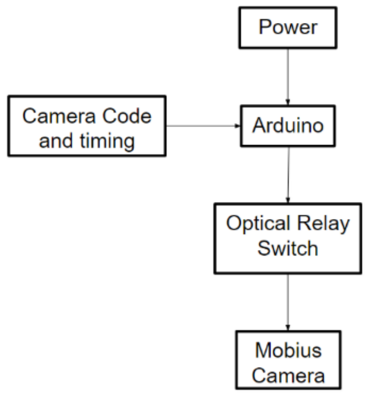

Figure 3: Mobius camera block diagram.

The MoCam block diagram is shown in *Figure 3*. Battery power is provided to an Arduino Pro Mini, which is loaded with timing for the camera. This Arduino controls an optical relay switch which turns the camera on and off as desired by the preloaded code, or as commanded by the Comms system (HASP).

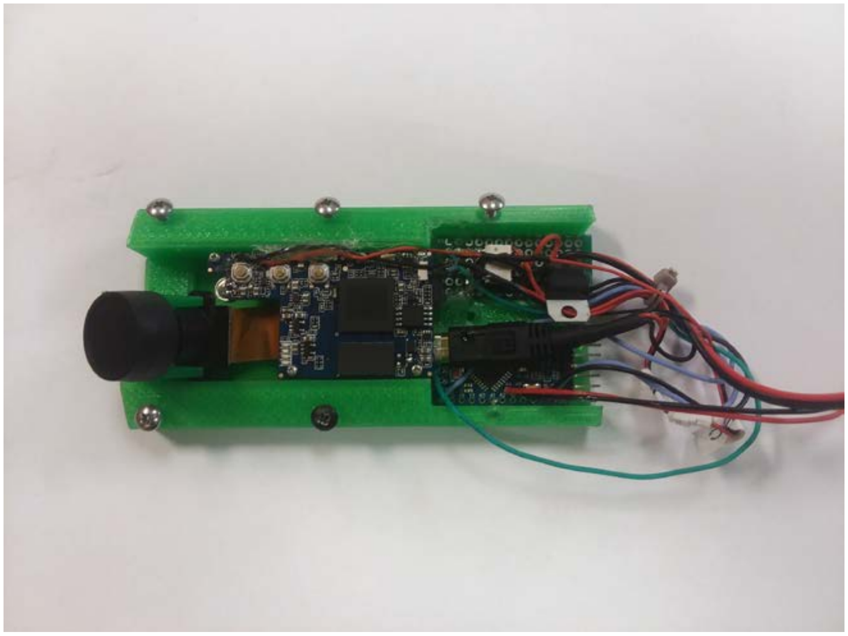

Figure 4: Mobius camera structure.

Figure 4 shows the MoCam structure. The camera, Arduino, and a small electronics board fit into their respective slots and are mounted with small screws. The green housing screws onto the inside of the outer cylinder and allows the lens to stick out of the main outer structure. The power and communications lines are easily unplugged to allow removal of the sled from the outer structure.

Figure 5: Actual Mobius camera structure and set up.

Figure 5 shows the subsystem mounted to the outer structure. The lens protrudes enough to allow full view of the flight while keeping the camera electronics protected.

3.3 Power Management System (PMS)

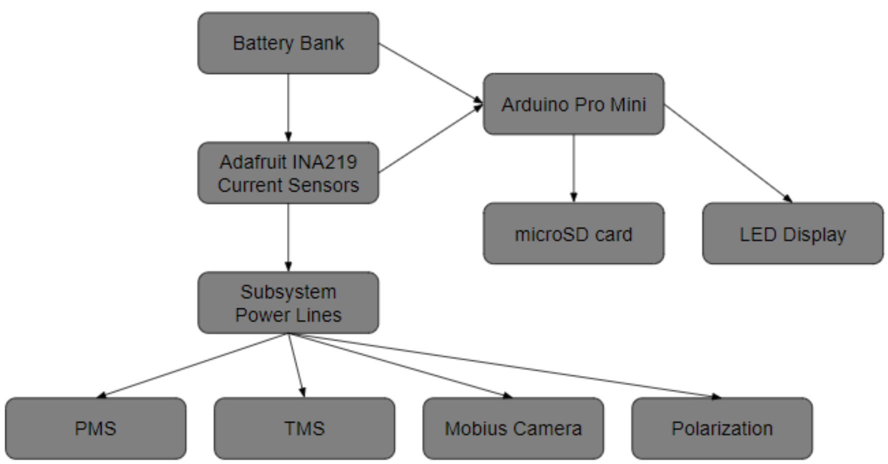

Figure 6: Power management system block diagram.

Figure 6 shows the block diagram for the PMS. Current sensors are placed inline between the battery bank supply lines and the individual system draw lines (PMS, TMS, Mobius camera and polarization experiment). The Arduino Pro Mini will write data from the current sensors to a microSD card, and control an LED display to provide quick external statuses for all systems.

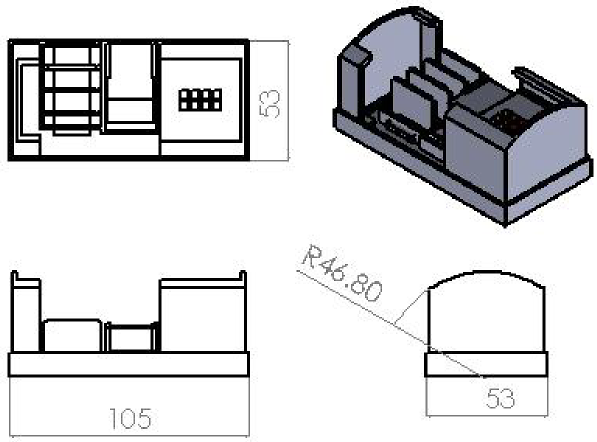

Figure 7: Drawing of PMS housing.

Figure 7 shows a sketch of the PMS housing. It is made to fit securely into the cylindrical tube with minimal fastening. The friction fit design allows the PMS to sustain a rocket or balloon launch.

3.4 Thermal Management System (TMS)

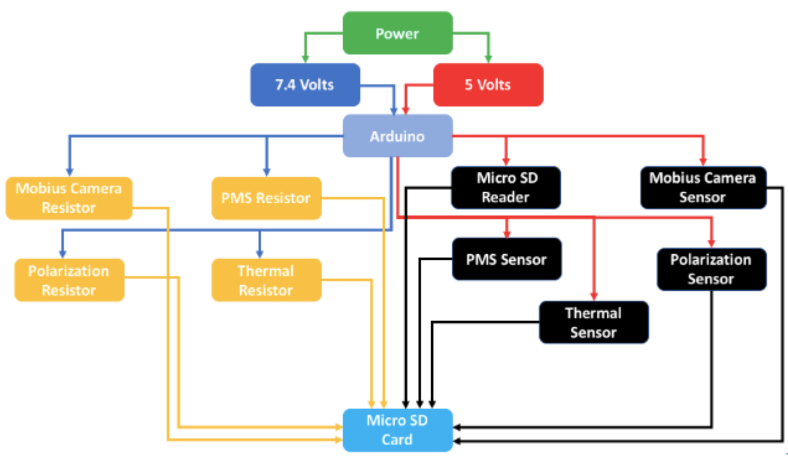

Figure 8: Thermal system block diagram.

Figure 8 shows the block diagram for the TMS. It is powered by 7.4 volt and 3.3 volt batteries; an Arduino Pro Mini reads temperature sensors from all components and turns on resistor heaters as needed when the temperature drops. All temperatures, heater statuses, and time is written to an internal SD card.

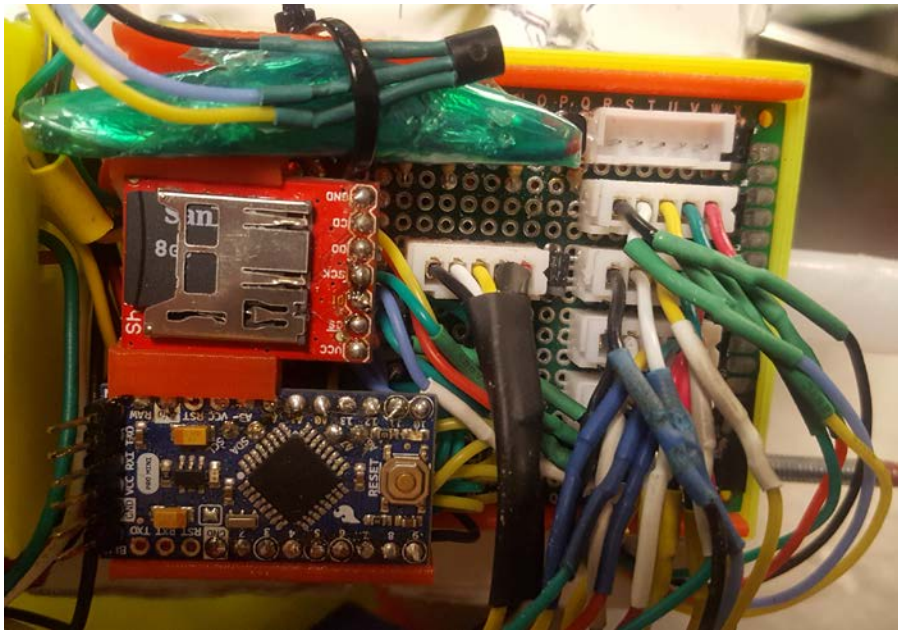

Figure 9: Actual picture of the temperature management system, with an extra 5-pin connector.

Figure 9 shows the built TMS and housing. An extra 5-pin connector was added for future use but was not used in the DemoSat launch. All boards are securely friction fit to the housing and can sustain rocket and balloon launches.

3.5 Comms

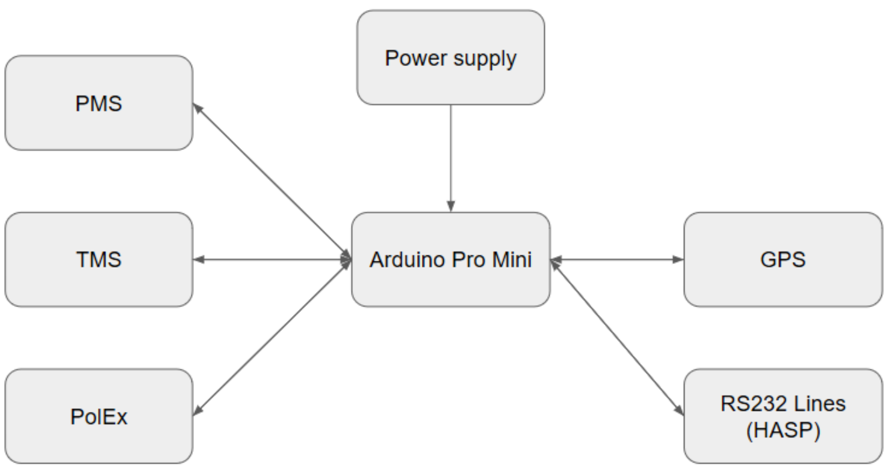

Figure 10: Comms block diagram

Figure 10 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 I^2C bus for intra-payload data transfer; and a UART serial bus to communicate with the HASP platform and for debugging / re-coding. 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.

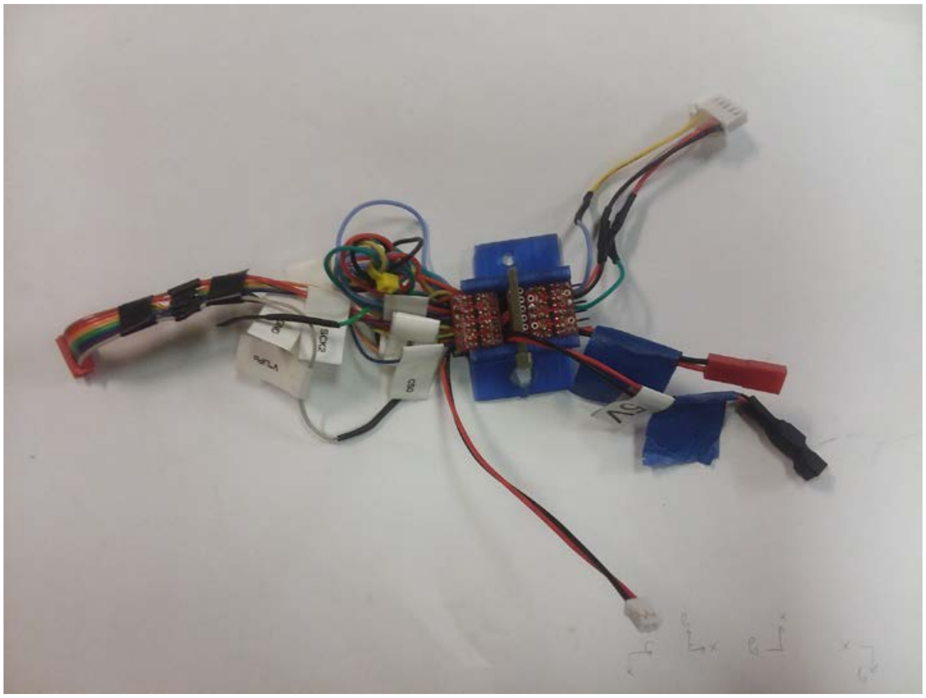

Figure 11: Comms structure

Figure 11 shows the completed subsystem structure, a 3D-printed PLA housing which fits compactly underneath the GPS on, and is mounted to, the payload sled.

3.6 GPS

Figure 12: GPS

Figure 12 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.

3.7 Structure

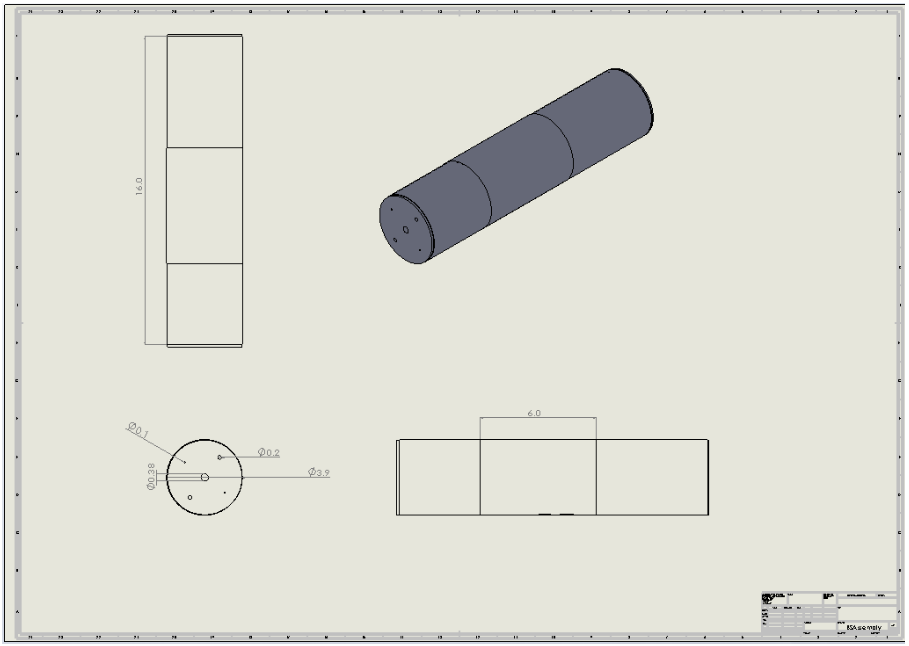

Figure 13: Outer structure drawing for DemoSat.

Figure 13 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.

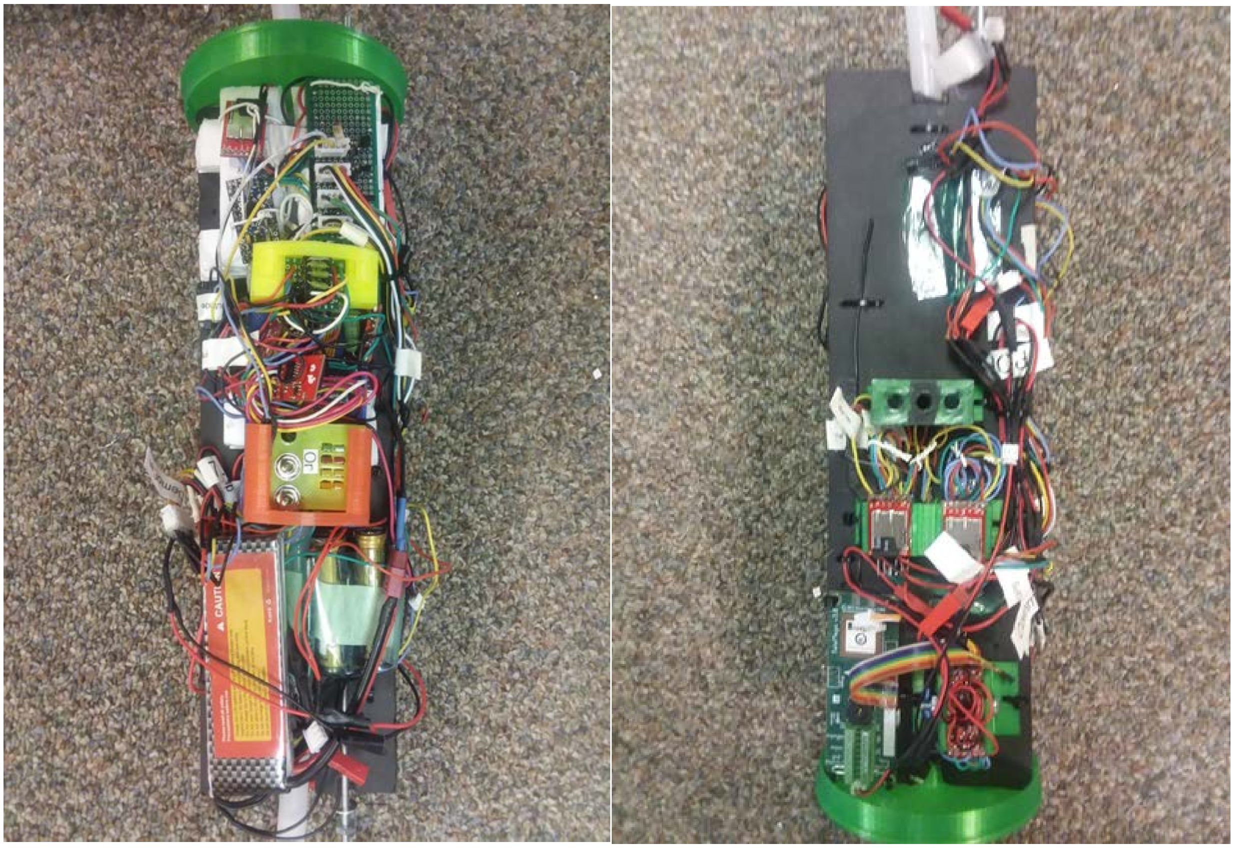

Figure 14: Inner "sled" structure for DemoSat

Figure 14 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.

4.0 Management

Table 1: Subsystem assignments.

Task	**Person(s) in charge**
PMS	Mark
MoCam	Nate
PolEx	Jodi
Structures	ALL
TMS	Jodi
Comms	Nate
GPS	Nate
Testing	ALL

Each team member will be in charge of a specific subsystem as shown in *Table 1.* However, the whole team is responsible for ensuring all subsystems work together and the whole payload is functional.

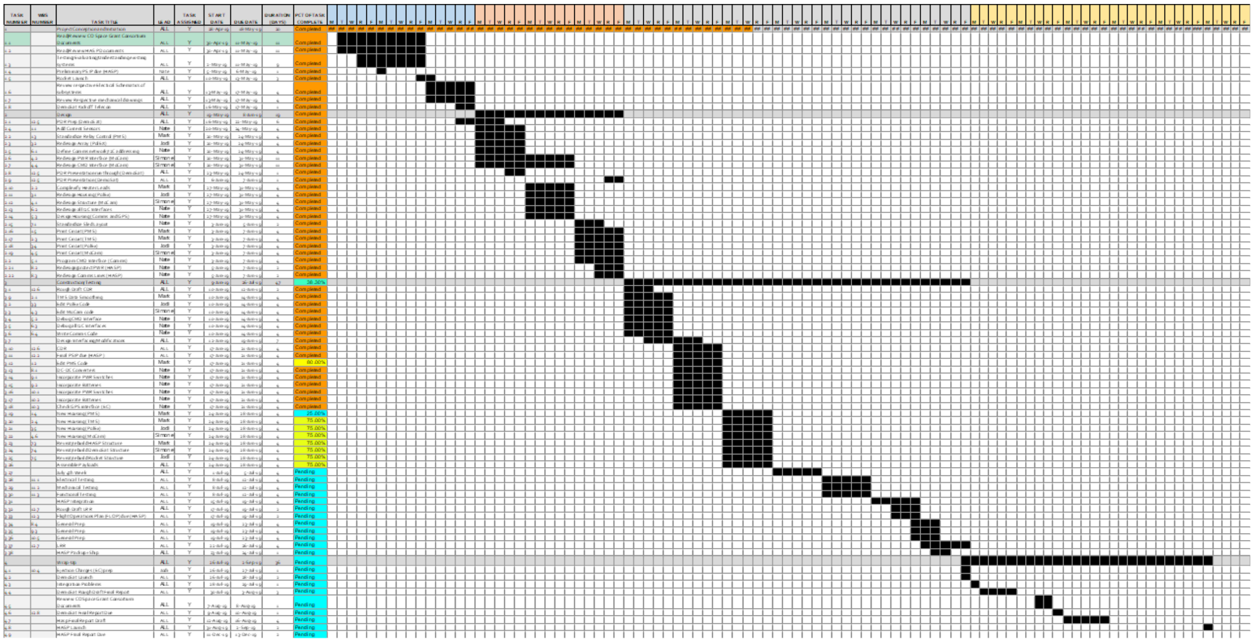

Figure 15: Gantt chart with milestones.

Figure 15 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 Balloonsat launch and HASP integration. This also forced the building of the two payloads to be overlapped as well as testing. Both payloads could be improved if building occurred earlier and there was more allotted time for troubleshooting.

5.0 Budget

5.1 Weight Budget

Table 2: Weight of components.

Sub-system	**Weight (g)**
Polarization Experiment	59.9
Batteries	177.8
Power Management	128.8
Temperature Control	48.4
Structure (outer, sled, inner tube)	214.7
Interpayload Communication	25.4
GPS	25.6
Mobius Camera	68.1
TOTAL	**748.7**

Table 2 shows the weight budget for the DemoSat payload. With a new thinner outer housing and thinner foam core sled, the team came in well underweight.

5.2 Financial Budget

Table 3: Weight of components.

Item	**Cost ($)**
Polarization Experiment ● Arduino, Altimeter, SD card reader, 9DOF board	$58.79
Batteries	$39.91
Altus Metrum TeleMega GPS Transmitter	$400
Power Management	$54.70
Temperature Control ● Multiple resistors/temperature sensors	$20.90
Structure ● Foam Board ● ⅜" ID tube	$5.00
Mobius Camera	$79.00
Miscellaneous ● Glue, wires, protoboards, resistors, etc.	$30.00
Various 3D printed parts	$20.00
TOTAL	**$708.30**

Table 3 shows the financial budget for the DemoSat payload. Large contributors to cost come from the GPS transmitter, mobius camera, and polarization experiment components. Most large components can be used again in rocket launches or on future DemoSat payloads. All housing components were 3D printed using the printer at FLC and small hardware pieces were purchased at ACE Hardware.

6.0 Test Plan and Results

6.1 Functional Testing

The team was granted access to 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 some other Comms issues for the duration. The payload was immediately modified to remove the connector from the design. The team considered this an adequate test of the payload concept.

The DemoSat payload was replicated using the HASP payload as a basis and was tested for functionality for several hours during the DemoSat Launch Readiness Review on Friday, July 26th. No outstanding issues presented, and the payload was cleared for flight.

6.2 Structural

On Friday, July 26th, the team also performed a drop test from approximately 25+ feet of elevation onto grass. This test demonstrated the structural integrity of the payload required during landing. No components were found faulted from the test.

7.0 Expected Results

7.1 PMS

Power data is expected to have current for all components and battery voltages written into a text file. A sample is shown below, with an included header to explain.

Time(s), PMSCur, MoCamCur&Comms,PolExCur&GPS, TMSCur, 8Voltbattery,4Voltbattery:

“1.96, 0.0127, 0.1574, 0.1144 ,0.0097 ,7.4129, 3.6968”

7.2 TMS

Temperature data is expected to have Time, heater status, and temperature readings for all components. A sample is shown below, with an included header to explain.

Time(s), Temp 1, Heater 1, Voltage 1, Temp 2, Heat 2, Volt 2, etc

“0.67, 99.41, 0, 1.49, 91.11, 0, 1.41,” etc

7.3 PolEx

Polarization Experiment data consists of two parts: the IMU sensor data, and the combined experiment array and barometer data. A sample of each is shown below, with an included header to explain.

timeinSec, AccelX, AccelY, AccelZ, GyroX, GyroY, GyroZ, MagX, MagY, MagZ
“4.61, 1.38,-7.77,8.71,-0.05,-0.15,-0.06,9.56,6.34,-38.38”

Time (s), Pressure (Pa), Altitude (ft), Hor_Pol_Read, Hor_Pol_Voltage, No_Pol_Read, No_Pol_Voltage, Vert_Pol_Read, Vert_Pol_Voltage, Norm_Pol_Horiz, Norm_Pol_Vert
“5.50, 3111.38, 70474.81, 87, 0.25, 132, 0.39, 109, 0.32, 0.66, 0.83”

7.4 MoCam

Mobius camera data is expected to be multiple video files written to the internal SD card. A sample of this can be seen from the Nov ‘18 DemoSat launch at this link: https://youtu.be/TNyETNj2hUU

7.5 GPS

GPS data is expected to have the latitude, longitude, and altitude of each position point in .kml format. When plotted, the result will be the traveled flight path.

“5,3985, 1, KE0NCG, 2916.79, 2936.11, 2147483647, 0, 1, 1, 4, 39.610719, -104.0419258, 1599, 2018, 7, 28, 12, 29, 49, 146341, 146342, 47, 0, 10.5, 9.3, 4.7”

8.0 Launch and Recovery

8.1 Pre-Launch

The payload was cleared for launch Friday, July 26th, after a Launch Readiness Review and team internal review. The payload was packaged for transport by the faculty advisor to the launch. The team all planned to travel to attend the launch in Limon, Colorado, the following day; and all planned to assist in recovery.

8.2 Launch

Fifteen minutes before launch, the team lead secured the payload to the flight string and activated the payload power switches. The team leads then assisted in hand-launching the payload as the flight string was released. The team then began tracking the payload, both via the launch provider's website and via the GPS downlink from the payload. While the GPS downlink was lost approximately 45 minutes into the flight (see 9.3), the team continued tracking via the launch provider's website until landing.

8.3 Recovery

At recovery, the payload outer structure presented nominal, having narrowly missed a windmill on landing. The payload was taken off the flight string and the power switches were turned off. The payload sled was removed, and all subsystem data was retrieved for later analysis. After recovery was complete, the payload was shipped back to FLC. Upon inspection back in the laboratory, the payload was fully intact besides the flight string; there was no external damage and all internal components were not harmed.

9.0 Results, Analysis, and Conclusions

9.1 Temperature System

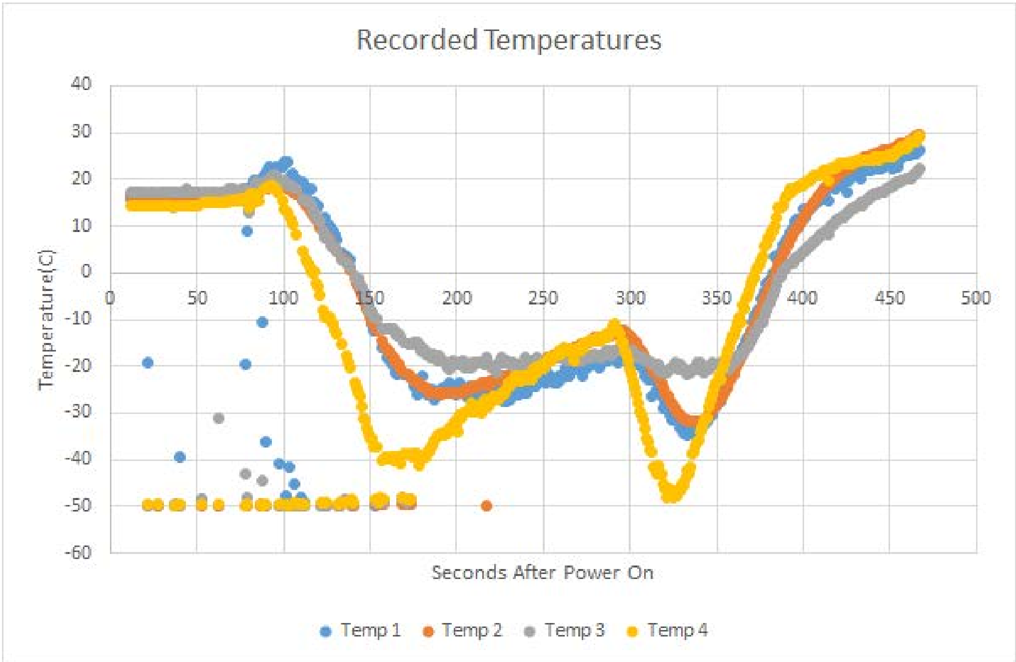

Figure 16: Temperature of all components.

Figure 16 shows the temperatures of all components on the payload. The temperature glitches at the beginning of the data were caused by interference from the GPS transmitter. According to the timestamps, the TMS only recorded the first 467 seconds of flight, however, the temperature reading appears to be from the entire flight.

9.2 Power Management System

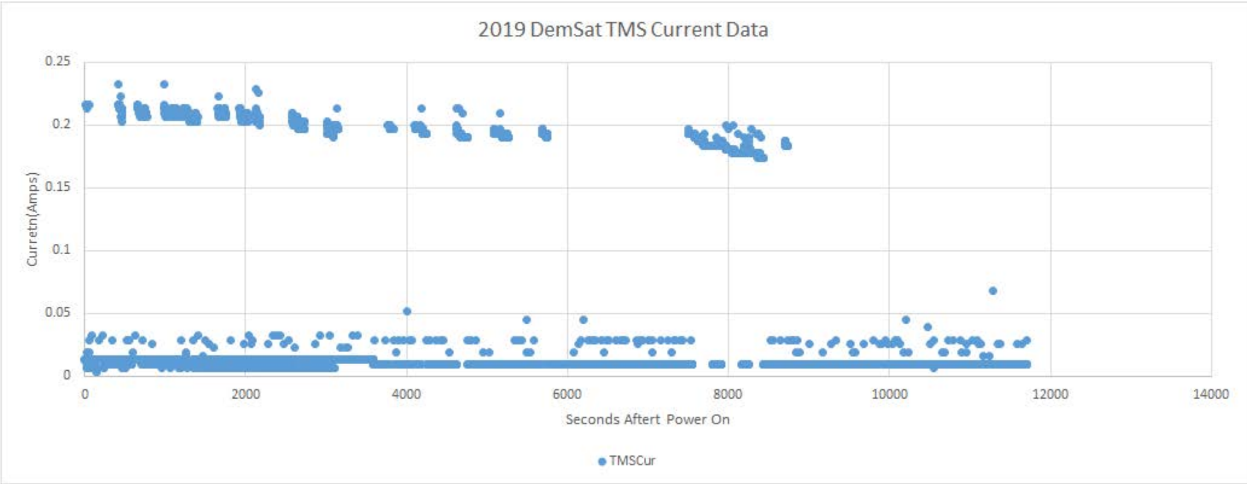

Figure 17: TMS current data.

Figure 17 shows the TMS current data for the flight. The most current was used at the beginning of the flight. This could have been because the temperature dropped quickly then warmed up as the payload descended and the air temperature warmed up throughout the flight.

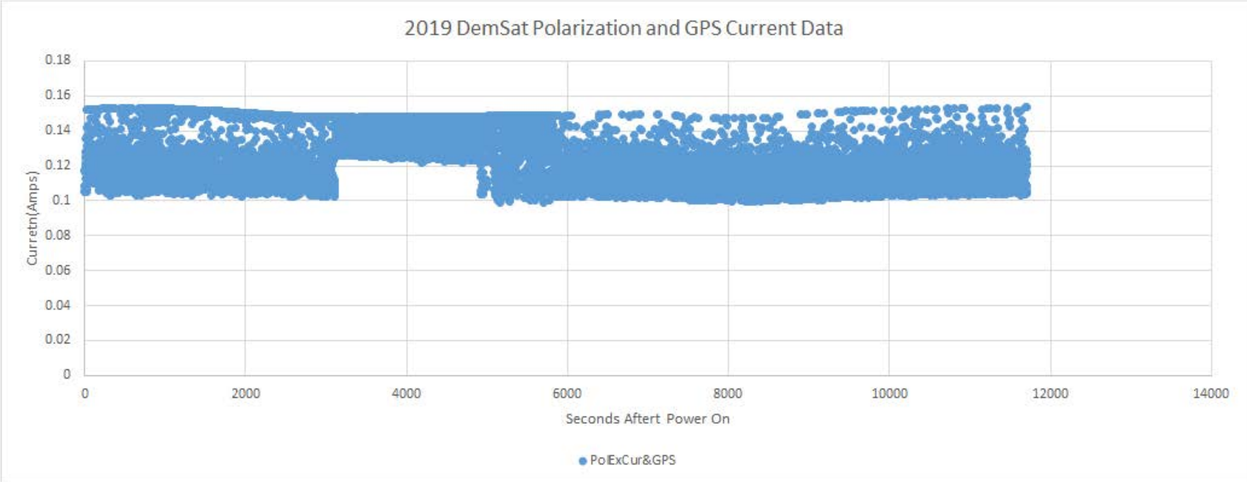

Figure 18: Polarization and GPS current draw.

Figure 18 shows the polarization and GPS current data throughout the flight. The current readings fluctuate widely, depending on whether the GPS was actively transmitting or not; but it remained within a constant range as expected.

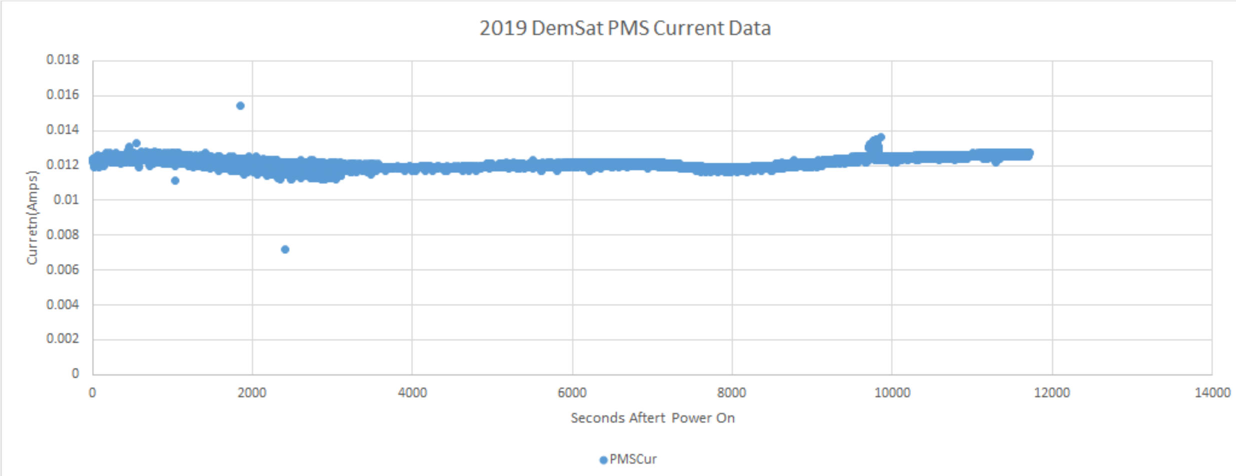

Figure 19: PMS current data.

The Power Management System (PMS) data is shown in *Figure 19*. It stays very constant with some drop off in the end. This could be because the MoCam stopped working early on during the flight, and the TMS had less current draw as temperatures rose after landing.

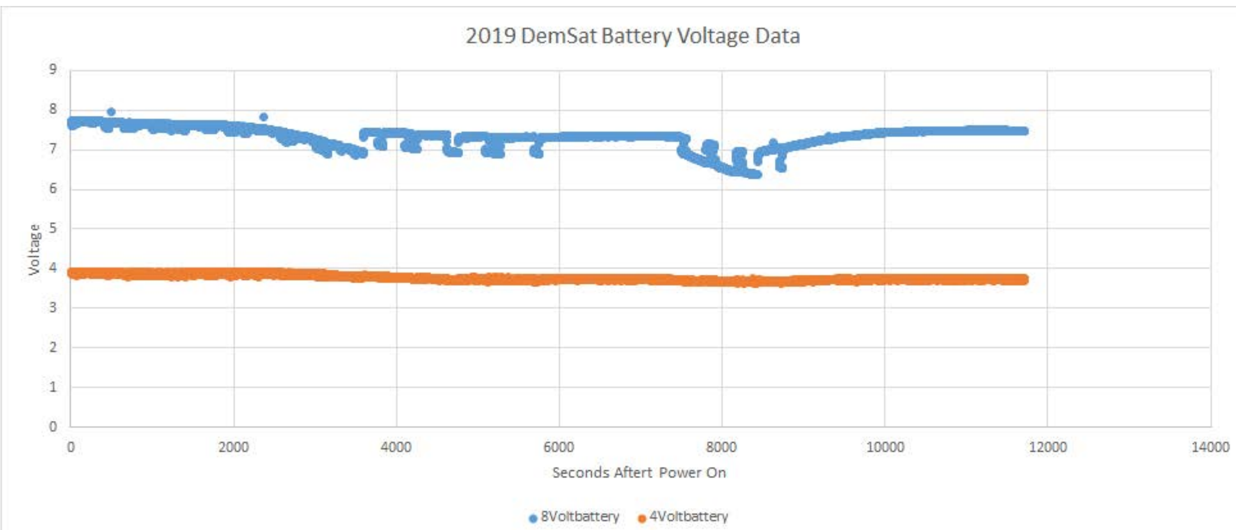

Figure 20: Battery voltage data.

The voltage of each battery is shown in *Figure 20.* The 4 volt battery has a linear decrease in output voltage. The 8 volt battery's voltage is much more dependant on the load that is applied. The downward fluctuations correspond well to the periods of an increased load from the heaters.

9.3 GPS

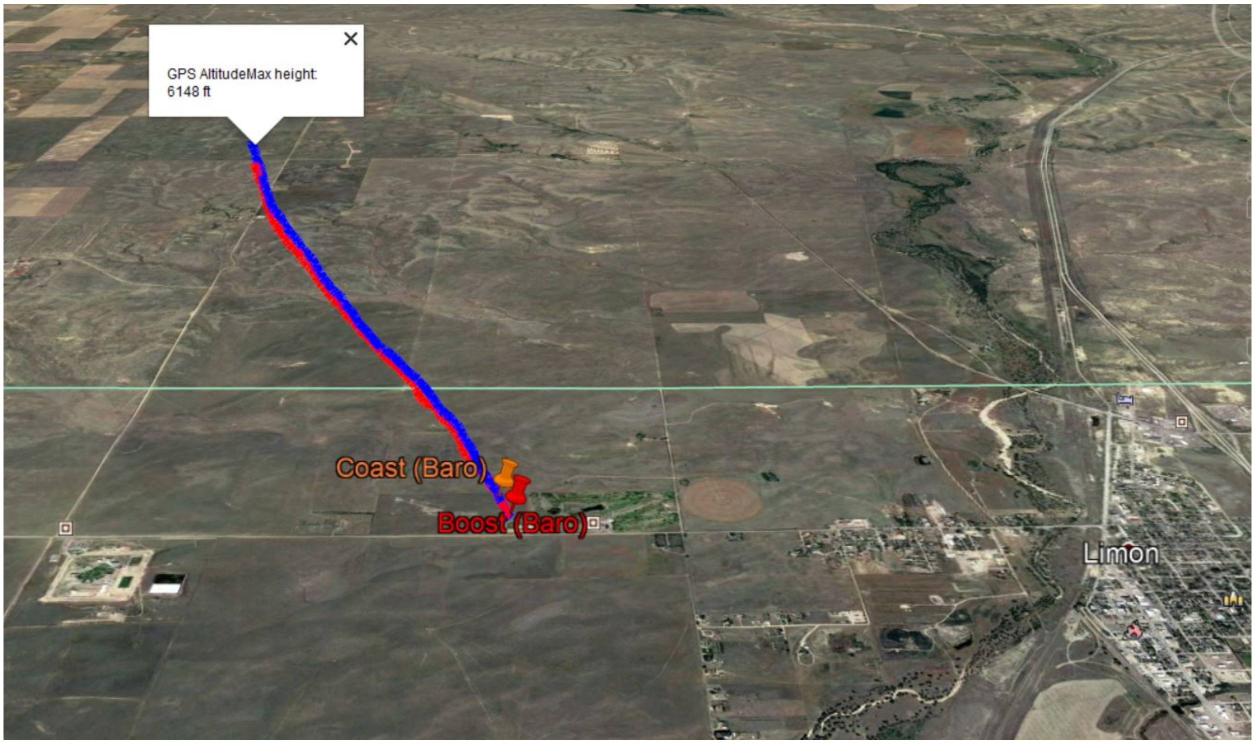

Figure 21: GPS altitude data.

Figure 21 shows the GPS data from the flight, and more specifically the flight altitude. The maximum altitude that was recorded to the KML file was 6184 feet above ground level. A post-flight analysis concluded that the batteries used to power the GPS throughout flight performed well underneath of their advertised specifications, and as a result the GPS ceased recording internally after ~2,350 seconds into flight. This corresponds to the approximate time when the GPS downlink ceased, due to a low voltage error signal.

9.4 Mobius Camera

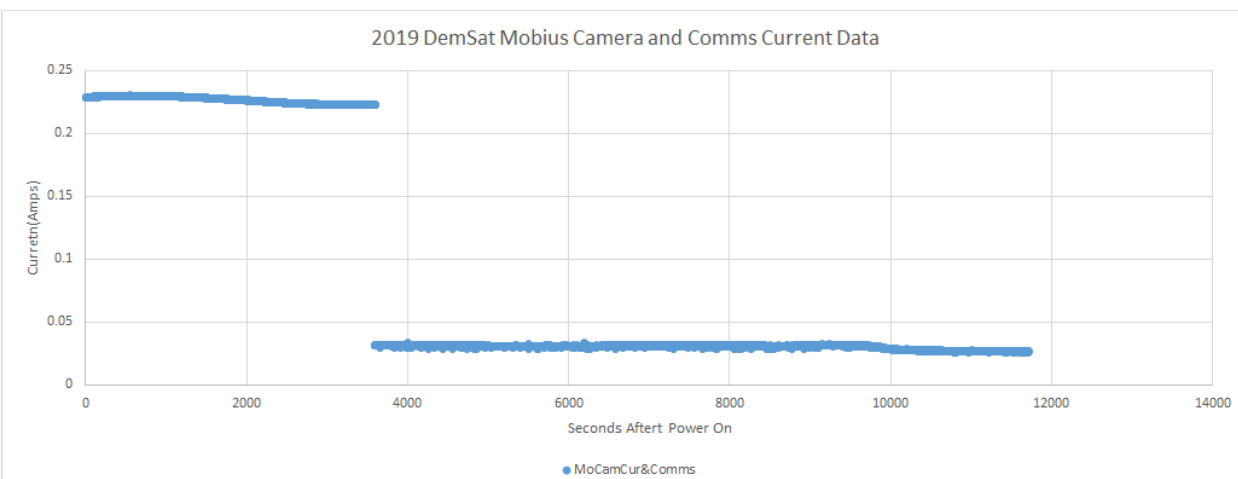

Figure 22: MoCam current data.

The Mobius Camera recorded video until one hour after startup, as shown by *Figure 22* by the sudden change in current. The camera shut down after an hour due to a coding error on the Arduino Pro Mini. The error has since been fixed to avoid replication of the error on the HASP payload. The video that was recorded can be watched using the following link: https://youtu.be/caEF2VV0z6E

9.5 Polarization Experiment

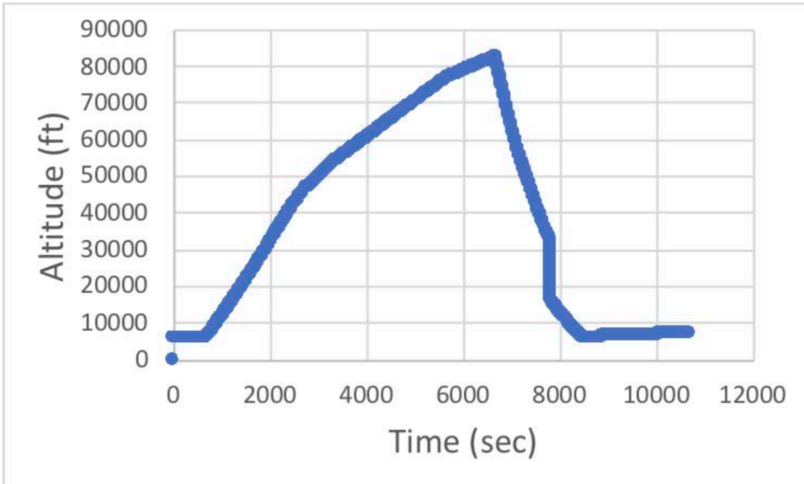

Figure 23: PolEx Altimeter flight data.

Figure 23 shows the altitude that was recorded from the altimeter located on the IMU. Due to the fact that the altimeter calculates altitude based on the surrounding air pressure, the accuracy of the altimeter decreases as altitude increases. This accounts for the discrepancy between the reported burst height by the altimeter (82,382 ft) and the launch provider (107,050 ft).

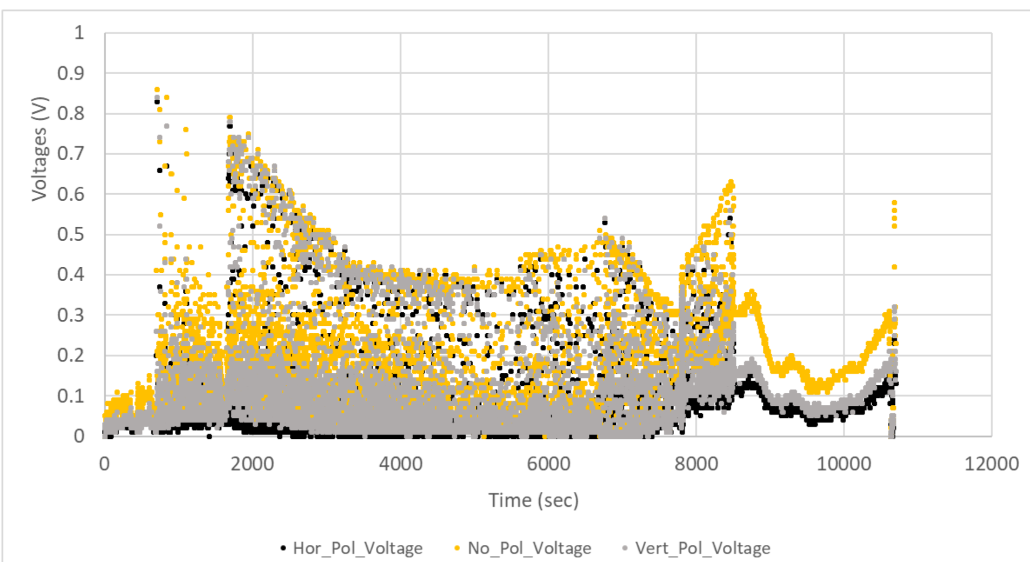

Figure 24: PolEx Array signal data.

Figure 24 shows the output voltage of the polarization sensors. The sensor that is not filtered with polarized film has a slightly higher average output voltage, as it receives unfiltered intensity throughout the flight.

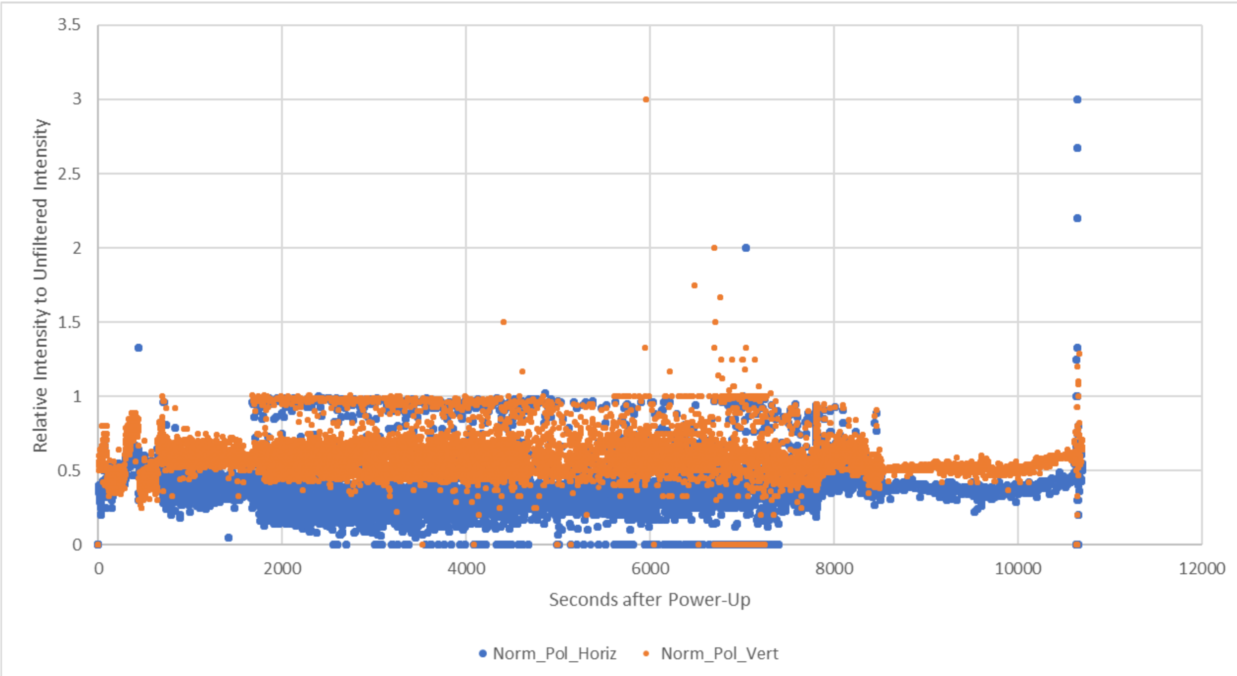

Figure 25: PolEx Array normalized signal data.

Figure 25 shows the normalized output voltage of the polarization sensors. The vertical polarization sensor has a typically higher average output voltage; this demonstrates that the majority of readings occurred with the vertical axis more closely aligned with the relative angle to the sun than the horizontal axis.

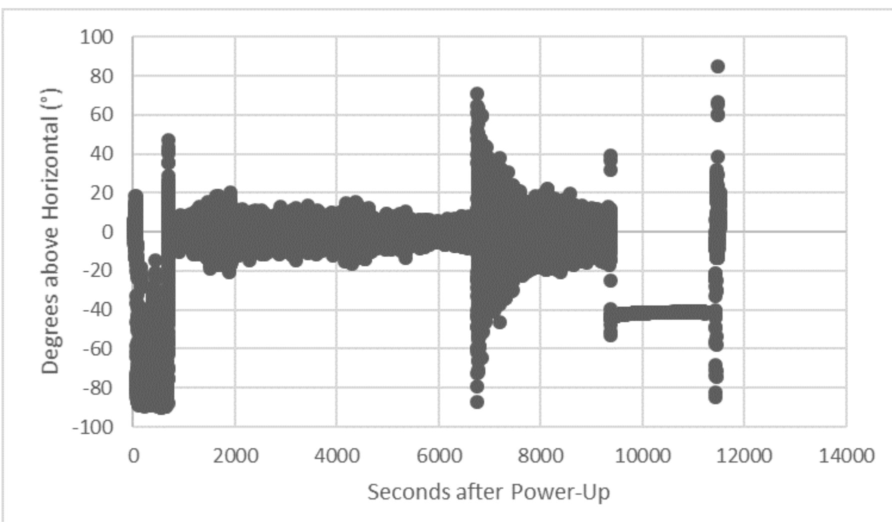

Figure 26: PolEx IMU pitch data.

Figure 26 shows the flight pitch orientation data, or array reference angle above the horizontal. As expected, a period of wild oscillations can be easily seen during descent, while ascent is relatively stable. A flat line after descent further denotes landing.

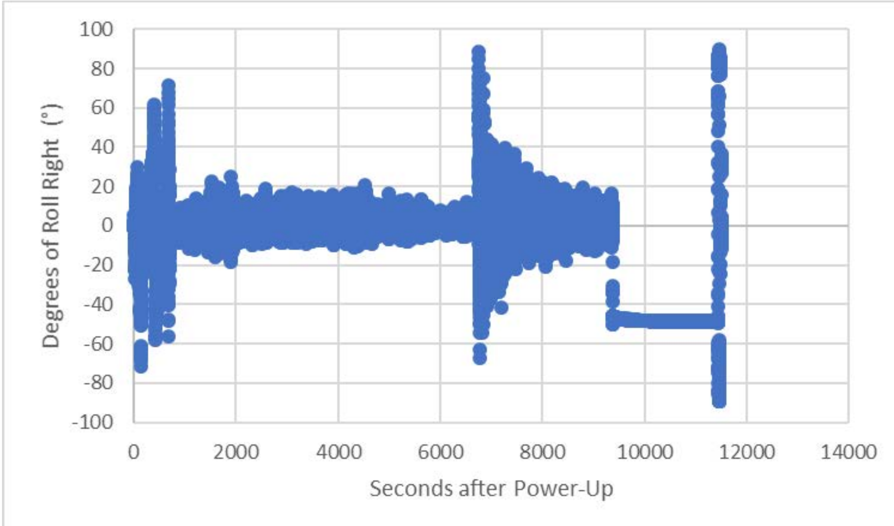

Figure 27: PolEx IMU roll data.

Figure 27 shows the flight roll orientation data, or array roll angle referenced to the horizontal. As expected, a period of wild oscillations can be easily seen during descent, while ascent is relatively stable. A flat line after descent further denotes landing.

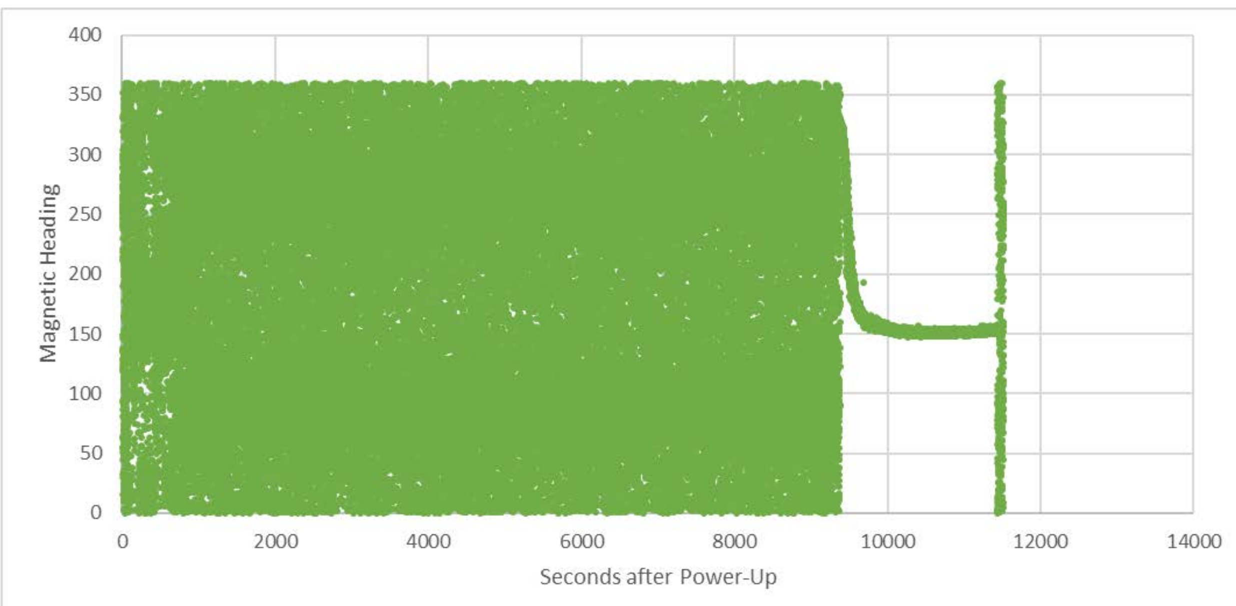

Figure 28: PolEx IMU yaw data.

Figure 28 shows the flight magnetic heading data, or array yaw angle referenced to magnetic North. The data shows that the payload gyrated along the flight string axis fairly evenly throughout flight. This is important, as it means that the PolEx array was able to consistently scan the full horizon. A flat line after descent further denotes landing.

9.6 Experiment Analysis

Due to data analysis technicalities, the full analysis of the returned PolEx data, and its significance is not yet available. Yet to be determined is the multi-variable relationship between the array angle, relative intensity, and altitude. This relationship allows a comparison of the atmosphere's ability to polarize the daytime Rayleigh scattering and the change in ability due to altitude over the launch site. Upon request, the team will send an updated version of this final report, including the full analysis, when this full analysis becomes available.

10.0 Ready for Flight

The issues discovered from the DemoSat launch have been remedied on the HASP payload, and the HASP payload is now ready for flight. The DemoSat payload will be stored with the batteries disconnected until its next flight. The payload may also be tested by launching on a local high-powered rocket; this would require remounting all components to a reinforced sled. To activate the payload: batteries need to be charged and connected, then the sled would be inserted into the main flight tube and secured with end caps. Activating the power switches would then render the payload ready for launch.

11.0 Conclusions and Lessons Learned

The team learned the difference between 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 when this is done again. However, the team came away from the summer with a greater understanding of aerospace systems and even managed to enjoy the experience.

12.0 Message to Next Year

The biggest thing that should be stressed to next year is to leave more time for testing and troubleshooting, and the tandem last-minute-modifications to fix the ever-present bugs. With building two payloads, more time should be left for troubleshooting and testing with each payload; each “similar” system will have unique quirks to be worked out. Additionally, the team had a number of software AND hardware issues that did not present in the prototyping stage, as the subsystems were not in their final form and were not tested simultaneously. To combat this, teams must remember systems thinking, and design components to survive “independent” component failures. Finally, the team should remember that while frustrating failures can occur, it is OK; it is better that they occur NOW than on the launch day of a space shuttle somewhere. Have a safe flight, next year.