RockSat-X 2022 Final Report

Project Imua Mission 10

University of Hawaii Community Colleges

To conduct research on the feasibility of using a sublimation-fueled motor for providing low-power vernier thrust. In doing so, UHCC students are encouraged to explore and engage in team oriented and problem involved engineering design, fabrication, and research.

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1.0 Mission Statement

Our goals are to encourage UHCC students to explore and enter STEM-based careers by engaging in team-oriented, problem-solving activities that emphasize the integration process involved in the design, fabrication, testing and documentation of launch-ready, space-bound payloads supporting scientific and/or engineering experiments. In doing so, we aim to conduct research on the feasibility of using a sublimation–fueled motor for providing low-power vernier thrust. The specific impulse of the sublimate camphor will be determined by a static ground test and by deploying the rocket from a sounding rocket at apogee. On board cameras will record the sublimation rocket's flight parameters. This data will be supplemented by an IMU and a multi-axis accelerometer that will provide a baseline for the payload's flight trajectory. In addition, a proof of concept test will be performed on a 1U Artemis CubeSat.

2.0 Mission Requirements and Description

To best calculate the specific impulse of Camphor the acceleration caused by the sublimation of Camphor needed to be known. There are several notable ways to derive this, but taking computational efforts into consideration; a simplistic method can ease this consideration. Additionally, keeping unnecessary complexity out of experimental design would yield greater chances of success.

Considering this, it was desired to set up a kinematic design in which the experiment would record distance and time data of Camphor's sublimation which can be used to calculate its acceleration. Under these restraints, the initial concept of the experiment would utilize a deployable sublimation rocket, named the Super Simple Sublimation Rocket or ScubeR for short, that would be deployed directly straight out of the CarRoLL section. In doing this, the deployed rocket would maintain the relative speed of the CarRoLL section, while also maintaining a forward deployment speed. In this instance, the sublimation of Camphor causes a net thrust and the deployment speed of the rocket would increase with respect to time.

To record this data, the experiment would utilize image recording equipment. Minimally, three photos at different times would yield workable results. However, a video recording of deployment was considered to be a substantial improvement. Considering that if an image capturing device would fail, all mission data would be lost, it was elected to have a redundant device that could aid in image collection. Conjoining these two cases, a video and additional pictorial camera were desired in design. Examining the first criteria of a straight deployment, it can be reasoned that these cameras would need to be positioned such that the sublimation rocket is observed to be straight. As such, this was factored as an additional criteria.

In the analysis of deployment, the methodology of deployment would need to ensure a total straight trajectory of the sublimation rocket. In the event that this straight deployment is not achieved, the sublimation rocket could experience an unexpected torque which would complicate the computational analysis of the experiment. To combat this, a guide rail was to be implemented to mitigate this concern. To help supplement this, a data controller was desired to monitor the parameters of the electronic payload deck. This would allow for further data analysis that could support the force analysis during the sublimation rockets release.

Considering the conditions of reentry, data loss due to reentry and water damage was a serious factor in design. Any digital storage device that would supplement data retrieval for the cameras would need considerable protection. As such, a watertight Hammond box was chosen to be utilized to provide this protection. With this in mind, the digital storage devices for the data controller and image devices were intended to be placed inside the Hammond box. In the event that sea water made contact with the interior electronics of the hammond box, the team implemented absorbers in the form of diapers that would soak up any water.

While incorporating these mission requirements during concept, secondary mission objectives were considered. During this process, a collaborative effort was made to strengthen Hawaii University system relations by incorporating the Artemis Cubesat from Hawaii Space Flight Laboratory into the experiment. Its purpose would be to serve as a proof of concept flight from the Cubesat. As such, the experiment's design would need to include enough space for the 10cm x 10 cm x 11cm Cubesat Volume.

3.0 Payload Design

General Design

With the mission objectives in mind, the payload was designed such that the sublimation rocket, ScubeR, would be deployed straight with respect to the CarRoLL section and the image capturing devices. The data collected would then be saved to micro SD cards that would be housed inside a pre-purchased Hammond Box.

In designing the experiment to meet the outlined mission requirements present in section 2, four critical subsystems were formed. They oversaw the power supply to the experiment, the deployment of ScubeR, the image data collection of ScubeR’s flight, and the supplemental data to be collected from the data controller.

Working with these subsystems, it was determined that placing the cameras above the deployment trajectory of ScubeR would meet the outlined mission objectives. Several designs were considered, and the final approved design involved the creation of a lens bridge that would be placed perpendicular to ScubeR's flight. This would allow for the cameras to be mounted to the bridge such that they could observe the straight deployment trajectory. While taking into account the location of ScubeR, the Hammnond box, and the Artemis CubeSat, it was determined to best utilize the provide experiment space the previously mentioned systems would be oriented such that the Hammond box and Artemis CubeSat could provide sufficient elevation to support the proposed lens bridge. In doing so, the lens bridge was fixed to the tops of the Hammond box and Artemis CubeSat which provided the necessary elevation to both clear and observe ScubeR's expected trajectory.

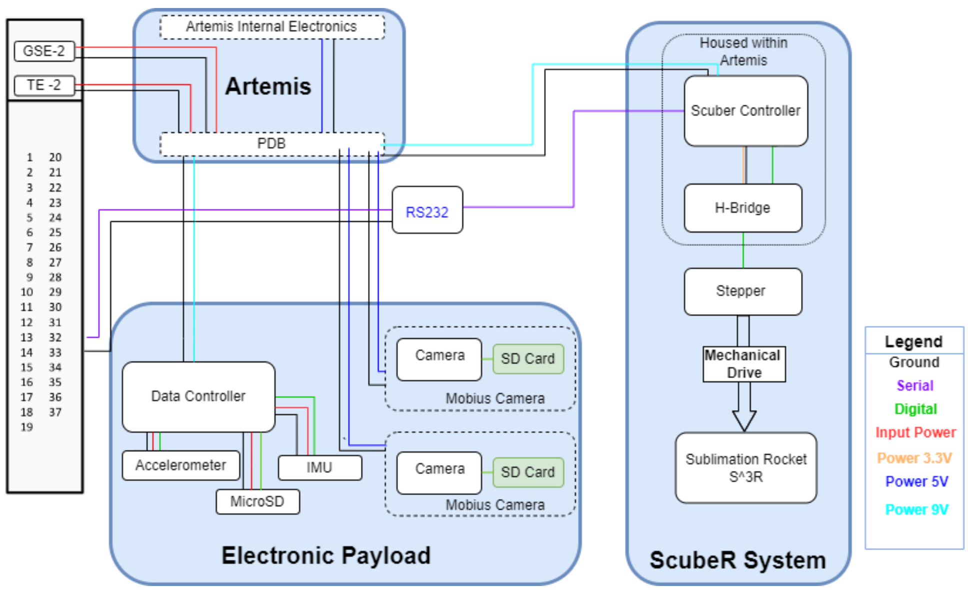


Figure 1. Functional Block Diagram.

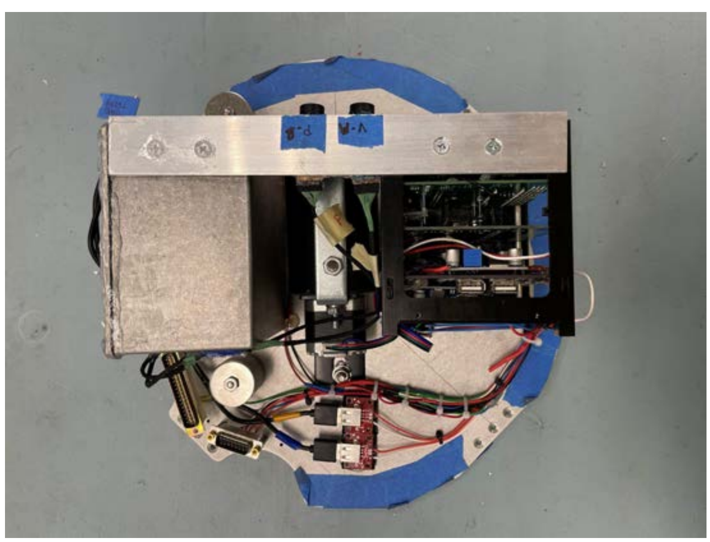


Figure 2. Top View of Payload.

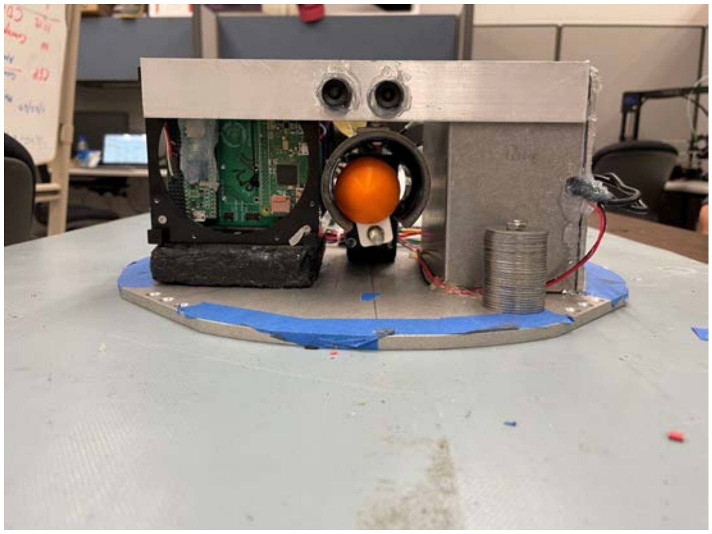


Figure 3. Front View of Payload.

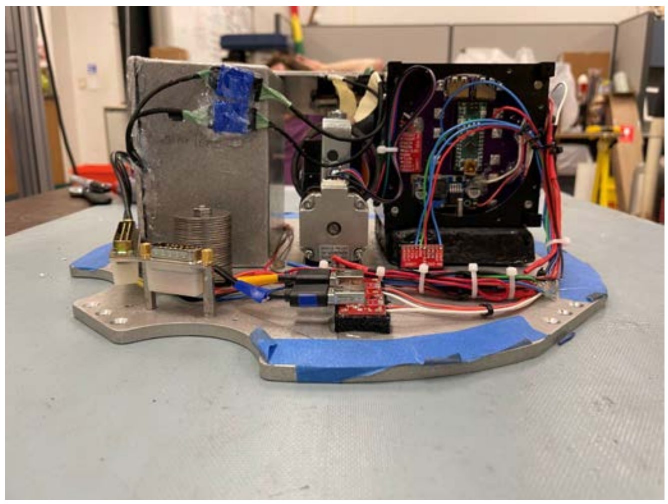


Figure 4. Back View of Payload.

Subsystem: Artemis

The Artemis subsystem consists of an inhouse fabricated power distribution board and the Artemis Cubesat.

The power distribution board was designed to fit inside the Artemis CubSat, and its electronics were intended to supply TE and GSE power to the entire experiment from the CarRoLL section. The final design utilized four DC to DC buck converters that supplied GSE power to the Artems Cubesat at T = -200 seconds and TE power to the Artmes Cubesat in addition to the ScubeR system, onboard camera, and data controller subsystems at T = +0.1 seconds.

The Artemis Cubesat comprises various data collection devices that remain undisclosed due to proprietary considerations. However, it was ensured that the

Artemis Cubesat met user guide standards during the design and fabrication process. These devices and the Cubesat's electronics were mounted to a Cubesat frame by fitting circuit boards to the four stands that compose this frame, Additionally, the power distribution board was mounted to the Arteis Cubesat by a similar means implemented the power distribution boards design.

Subsystem: ScubeR System

The ScubeR system is composed of the sublimation rocket ScubeR and its deployment apparatus.

ScubeR is made of three 3D printed parts that encompass a mass of Camphor. These pieces were fixed together using epoxy to ensure that ScubeR remained an integral unit during its flight. The Nose Cone and body parts of ScubeR were hollow to allow space for the sublimate Camphor to be placed inside of it. The third part was the nozzle which was created to allow the sublimation process to produce a thrust for ScubeR. Additionally, the body of ScubeR was created with two rail guide handles located on the underside of the body. These handles would allow ScubeR to be guided along the stepper motor during employment. Additionally, the handle located to ScubeR's aft included a mounted flange nut that would provide a means for the drive screw to impart a constant forward velocity to ScubeR. In doing so, the flange nut feature of ScubeR and the drive screw would serve to deploy ScubeR with a straight trajectory from the experiment section of the CaRoLL.

The deployment apparatus consists of a drive screw stepper motor which receives commands to turn clockwise or counter-clockwise from an H-bridge. The H-bridge itself is controlled by a script that is executed from an Arduino Uno. The layout of this subsystem allows the Arduino Uno to implement precise rotational control of the stepper motor at key times during the experiment. Additionally, A guide rail made of PCP pipe was mounted around the drive screw to prevent any unexpected torque to act on ScubeR during its deployment.

In consideration of the desired straight trajectory of ScubeR, the Arduino Uno utilized a script that would begin executing forward turns of the drive screw after initial ACS corrections at apogee. This ensured that ScubeR was deployed straight with respect to the experiment's cameras. Additionally, at T = +0.1 seconds, the Arduino script executed backward turns of the drive screw to ensure that any forward motion of ScubeR during the ascent to apogee wouldn't derail it.

Subsystem: Onboard Cameras

There are two onboard Mobius Action Cameras which will record imagery of ScubeR deployment. Camera one will be set to photo mode and will take multiple time-lapse photos of ScubeR in every two seconds. Camera two will be set in video mode and take a five-minute video clip to record the journey of the experiment from which power turns on at T+0.1 seconds to T+336 seconds which power will shut off. Both Camera lenses are attached to our Camera Lens Bridge that runs across from the Hammond box to Artemis (WINCC Power Distribution Board) and the camera lenses are positioned above ScubeR to capture the deployment. Data from both cameras will be stored with their respective MicroSD cards and both circuit boards will be stored in a waterproof Hammond box. The objective for this camera is to capture consecutive multiple images of the ScubeR deployment and use the imagery to calculate the acceleration of the ScubeR.

Subsystem: Data Controller

The data controller consists of an IMU and accelerometer. Data was stored in a microSD card that was recovered after the launch. An Arduino Nano Every acted as the microcontroller and the IMU had its accelerometer set to ±2g, gyroscope set to 245dps, and magnetometer set to 4 gauss. The other accelerometer was set to ±16g to measure high vibrations of the deck plate. The data controller got power at T+0.1 seconds and turned off at T+336 seconds, stored in a waterproof Hammond box mounted on the electronic payload deck plate adjacent to ScubeR's housing.

Mass and Monetary Budget

The experiment was designed to meet the conditions of a half experiment deck. As such, the experiment needed to weigh 15 pounds with an allowed deviation of 0.5 pounds. In fabricating the subsystems, their combined weight totaled 6.52 pounds. To combat this, a dead weight made of lead was created with a weight of 8.48 pounds and it was to be located just under the Artemis Cubesat.

UHCC - Weight Budget (Integrated Subsystems)	
Date: 4/30/22	
Subsystem	Total Weight (lbs)
ScubeR (and Guide Rail)	0.8
Artemis	0.78125
Lead Block (Dead Weight)	6.093715
Hammond Box with Cameras	1.54375
Screws, Washers, and Deck Plate (Dead weight)	~5.781
Total	~15
Over/Under (15 lbs)	~0 +/- 0.5

Figure 5. Weight Budget.

During the determination of the lens bridge height, it was understood that the experiment would be underweight. As such, this dead mass was accounted for during design and fabrication.

To fund the experiment, 83,453 dollars was budgeted for the creation of the experiment in addition to student funding, travel, and launch deposits. Overall, this budget proved to be sufficient for these endeavors.

Expected Data

In the event that ScubeR were to be deployed without a thrust, it would be expected that its speed after leaving the CarRoLL section would be the same as the deployment speed of the drive screw. Considering this, ScubeR would be observed to maintain a constant speed of 1 centimeters per second. However, if there was a thrust, the speed of ScubeR would be expected to increase as Camphor's sublimation would be providing an acceleration due to an overall thrust. Taking this into account, it was expected that the cameras would record a nonlinear speed of ScubeR as it would be experiencing a thrust.

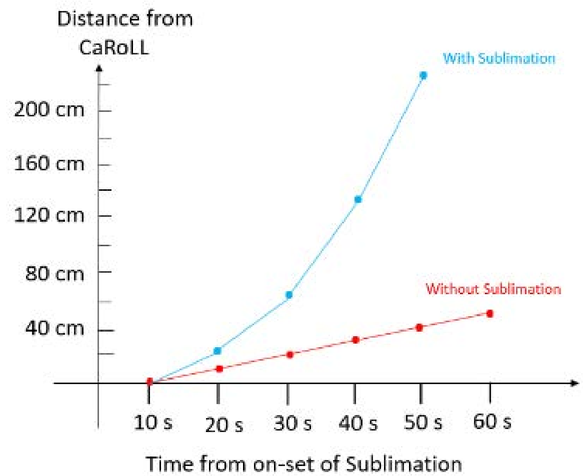


Figure 6. Early estimates of distance versus time data comparing sublimation providing a thrust in blue, and a non-thrusting deployment in red.

Additionally, a series of vacuum pressure tests were conducted to both ensure a less than 1 inch per second deployment speed of ScubeR, and to have early data estimates of Caphor's thrust. In doing so, ScubeR's thrust was estimated to be 521 microNewtons with a mass loss rate of 1 gram per hour.

4.0 Student Involvement

Jared Estrada - Project Manager, Physics Major
Nikki Arakawa - WinCC Team Lead, Electrical/Mechanical Engineer, Electrical Engineering Major
D'Elle Martin - HonCC Team Lead, Environmental Design/Architecture Major
Caleb Yuen - Electrical Engineering Major
Michelle Bolanos, IV - Prototyping and Data Processing, Physical Science Major
Deysha Childs - Data Analysis and Support, Astrophysics Major
Chris Noon - Artemis Cubesat Division, Team Lead, Highschool Student
Mason Pimental - Artemis Cubesat Division, Engineer, Highschool Student

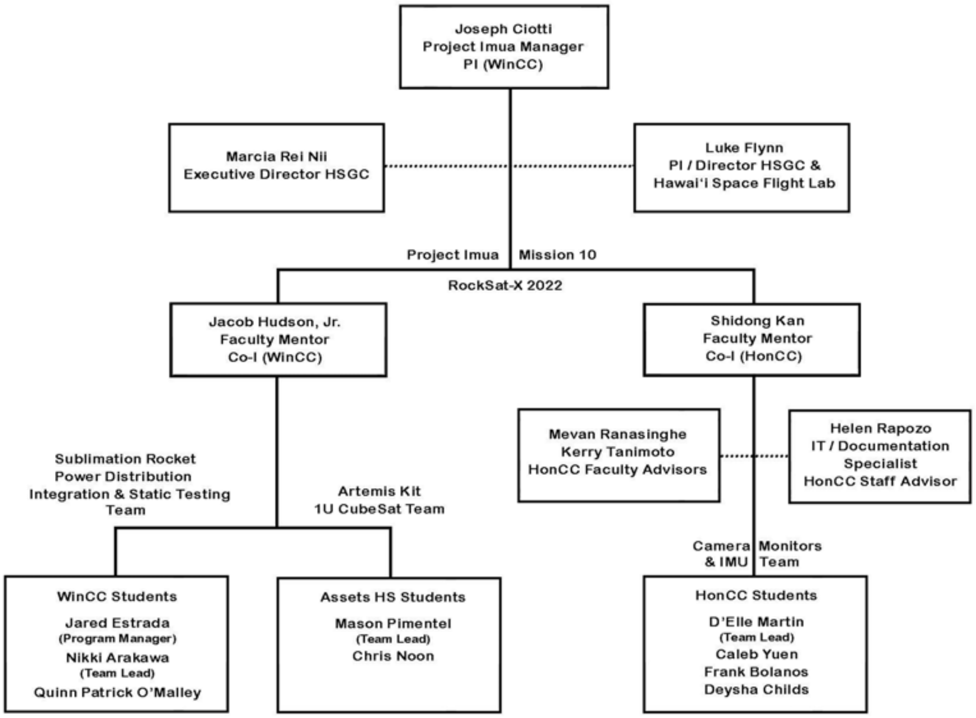


Figure 7. Team organization flow chart.

Figure 8.1. Team photo A—UHCC.

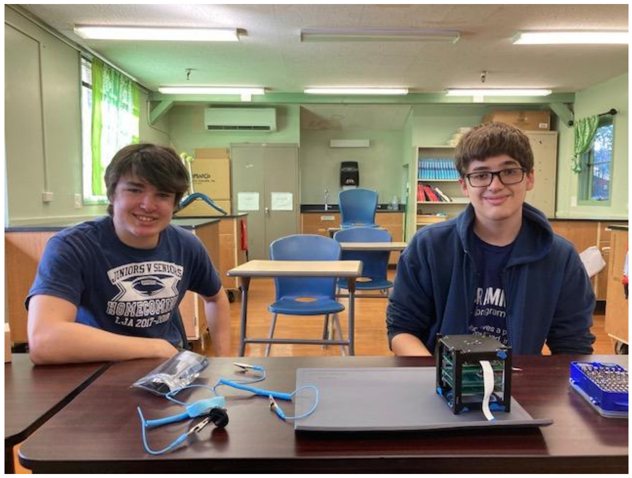


Figure 8.2. Team photo B—Assets HS

5.0 Testing Results

The graphic below indicates the general testing procedure that the designed experiment underwent to prove its capabilities. A few critical processes in the testing phase were ensuring that power could be supplied to all subsystems, the timing of ScubeR's deployment in the ScubeR subsystem, and the seeing integration success of the Camera and ScubeR subsystems. These categories would be broken into a series of power tests, a motion and timing test, and the image capture test.

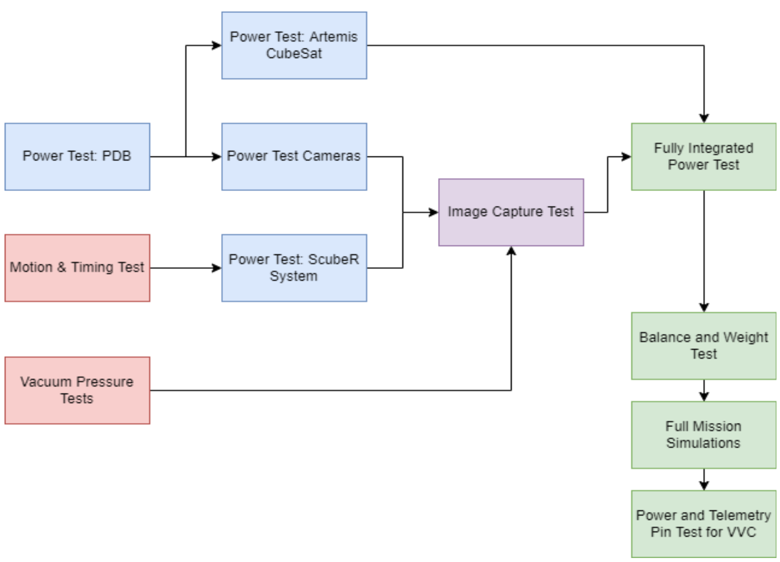


Figure 9. Testing procedure and layout. The blue boxes represent the power test series between individual subsystems. The red boxes pertain to the ScubeR system, and the single purple box symbolizes the merger between these two series of tests. Additionally, green boxes are the fully integrated tests.

Power Test: Power Distribution Board

This power test was designed to examine whether the PDB could receive power at the allocated 28V and 32V from an external power supply.

The power distribution board had successfully passed this test. No action was taken at this time, and the PDB moved onto conducting the rest of the power tests.

Power Test: Artemis Cubesat

This power test was performed to see if the power distribution board could supply the Artemis Cubesat with enough power to turn it on. This test was conducted three different times as the PDB was unable to power the Artemis Cubesat for the first two tests.

These initial tests had failed as various documentation iterations of the Artemis Cubesat did not contain clear instructions as to how the unit received power. So, the circuit layout of the boards was analyzed by utilizing a voltmeter and precariously testing various inputs. After the second test, the correct circuitry to supply power to Artemis was found and the power distribution board was connected to this layout. In then supplying external power, the PDB was able to distribute the sufficient power to the Artemis Cubesat to turn it on.

Motion & Timing Test: ScubeR System

Upon successful fabrication of ScubeR and its deployment apparatus, the ScubeR system was tested to ensure that ScubeR could move forward and backward along the drive screw. This was done by programming a simple script which allowed the Ardinuo Uno to turn the drive screw such that it could push ScubeR forward, and then backward. Upon mounting Scuber to the deployment apparatus, this behavior was successfully observed.

With the motion of the drive screw confirmed, a script was created such that the drive screw would perform quarter-back turns for a period of time and then execute full forward rotations which would lead to the deployment of ScubeR. This script was created and the ScubeR system successfully performed this task.

The timing aspect of this test needed to align such that the quarter-back turns occurred up until major ACS corrections had halted at apogee. Immediately afterward, the script needed to perform the forward command only until ScubeR was to have been deployed. This exact nature of this timing sequence underwent various changes due to ACS time changes in early versions of the manifest. The final timing sequence can be observed in the graphic below.

T = +0.1s	ScubeR Controller to give H bridge command to power motor, level shifter turned on via TE-2 and TE-R through PDB.
T = +103s	ScubeR Controller to start full backwards turn step command towards puncturing sublimate chamber for experiment start
T = +107s	ScubeR Controller to start full forwards rotation command (after ACS)
T = +118s	ScubeR is released from the shaft (deployed)
T = +123s	ScubeR Controller to complete command cycle and cease all commands

Figure 10. A layout of the timing script detailing critical sequence for the deployment of ScubeR.

After this test was performed, the manual installation and inhibition of ScubeR was performed to ensure these methodologies were viable. This was done by installing a screw into the stepper motor, which could be turned clockwise or counter clockwise that would correspondingly catch ScubeR and push it either forward or backward along the drive screw. In performing these tasks, the installation and inhibition of ScubeR was successful.

Power Test: ScubeR System

Like the other power tests, the power distribution board was connected to the ScubeR system which consisted of the deployment apparatus and a mounted final prototype of ScubeR. Upon supplying external power, the PDB was able to distribute sufficient power to turn on the ScubeR system. An additional criterion of this test included observing whether the PDB could power the ScubeR system long enough to observe execution of the timing script that would lead to ScubeRs deployment. In doing so, the ScubeR system was able to successfully simulate a deployment. No other action was taken at this time.

Power Test: Cameras

This test was designed to confirm that the power distribution board could supply sufficient power to the camera subsystem. In conducting this test, the PDB was able to successfully perform this task. No further action was required.

Power Test: Data Controller

This test was also designed to confirm that the power distribution board could supply sufficient power to the data controller. In conducting this test, the PDB was able to successfully perform this task. No further action was required.

Preliminary Testing: Data Controller

The data controller was tested from the lab unit to the final printed circuit boards. The accelerometers were tested through dropping the lab unit and through model rocket flights at Windward Community College. Using a turning table, the gyroscope was tested on each axis (x, y, & z) and the magnetometer was tested with a magnetic sensor. These tests aided in the data analysis of the results.

Vacuum Pressure Test

Upon the fabrication of a ScubeR prototype, samples of Camphor were placed inside of a vacuum chamber to obtain early estimates of ScubeR's performance, and the mass loss rate of Camphor. Additionally, these early measurements aided in ensuring that the initial velocity of ScubeR would remain under the required one inch per second. The first vacuum pressure test yielded optimal results and met our testing criteria. Several additional vacuum pressure tests were performed to support the results of the first test while also providing more data points to strengthen estimates of ScubeR's performance.

Image Capture Test

To test the camera system the team mounted the photo and video cameras on a stand above an air track, mounted a prototype of ScubeR on top of the air track sled, and captured images and video of the back of ScubeR at 5 cm intervals down the track away from the cameras. The photos and still images taken from the video of the back of ScubeR were measured using GIMP image software. The diameter of the image in pixels was plotted against the distance from the cameras in cm. This was done to verify that the images received correlated to the distance ScubeR had traveled. Next, the team set up photogates and added a pulley and counterweight to simulate a constant impulse and measure the acceleration. The team did 5 test runs of the set up to obtain an average acceleration for the set up, then took photos and images of the 6th run with the cameras. The photos occurred at known time intervals, and the video was given a timestamp. The diameter of Scuber in pixels was plotted against time, from which we were able to obtain a rate of acceleration. The process was repeated with the video data to verify both methods have the same results. The main take away from the testing was that the method was successful in obtaining an acceleration from image data. The team also learned the best method for accurately measuring and interpreting the data.

Fully Integrated Power Test

This test oversaw the electrical integration of all payload subsystems with the purpose of observing the functionality of all subsystems objectives. An external power source supplied power to the power distribution board. In doing so, the PDB was able to distribute power to all connected subsystems. In performing this test, the Artemis Cubesat turned on, the stepper motor of the ScubeR systems executed its timing script, and the mounted ScubeR was successfully released from the stepper motor at the appropriate simulated launch time. After power was turned off, the data on the cameras was observed and the pictures and video data were ideal. In conclusion, all subsystems were observed to be fully operational.

This test was performed three more times after this initial test to ensure the operational functionality of the payload. These tests were conducted after several mechanical alterations were applied to the payload. These alterations included the mounting of the subsystems to the deck plate, mounting procedures, an external rewiring of subsystem electrical connections to utilize available space, and the installation of the power and telemetry pins. The results of all sequential tests confirmed full payload operation.

Balance and Weight Test

The weight test was performed after full mechanical integration, in addition to the balance test. The weight of the payload was confirmed to be 15 pounds by using an industrial scale. With this measurement, the payload was confirmed to meet the weight requirement of the payload.

The center of balance test was conducted by placing the deck plate on top of the side of a rod. Any excess weight would cause the payload to tilt and fall off the rod. In performing this test, the payload was slightly off balance. To combat this, an amount of the budgeted dead weight was allocated to adding various dead weights across the deck plate to ensure proper balance. This was done by screwing countersunk screws into critical locations at the bottom of the deck plate. Hex nuts and washers were then utilized as dead weight and were placed to ensure appropriate balance. In doing so, the payload was confirmed to meet the appropriate balance requirements.

No further action was taken after these tests were completed.

Full Mission Simulations

Upon successful mechanical integration, two full mission simulations were conducted to ensure the full mission operation of the payload could be performed. These simulations saw power being supplied to the payload for the allocated operational times. GSE power was supplied to ensure that the Artemis Cubesat turned on, and only that subsystem turned on for the allocated 200 seconds. This behavior was observed in performing this portion of the simulations. Afterward, TE power was simulated to be applied to the entire payload for TE duration. The length of this duration was from T = +0.1 second to experimental section power off at the estimated T = +336 second mark. During this time, ScubeR was successfully released at the appropriate time outlined in its deployment script. Afterward, power was disconnected from the payload, and the micro SD card that stored the camera's data was examined via an external usb cable connection. In doing so, the image data was able to capture clear visuals of the simulated experiment. These results were consistent in conducting a second full mission simulation. As such, the full mission simulations were deemed successful.

Power and Telemetry Pin Tests for VVC

Mechanical integration of the power and telemetry pins marked the final alterations made to the payload. In doing so, a power supply and voltmeter were utilized to ensure correct voltage readings for each of the payloads assigned pins. At the time, this was deemed to be successful. However, later investigation during the GSE tests observed a mis-assignment between the electrical connection of the payload and the appropriately assigned pins. With a considerable amount of effort and assistance from Rocksat, this issue was resolved and the voltage across the pins was verified.

6.0 Mission Results

In terms of functionality, all subsystems performed their tasks successfully. The team received both images and video of the deployment of ScubeR. The video data collected also served to provide auxiliary data to the College of the Canyons, as the video was shared to assist in the CoC team’s data analysis.

ScubeR’s Flight Performance & Analysis

A critical adversity occurred in the analysis of ScubeR’s trajectory. At the time of deployment, ScubeR was observed to be executing a straight trajectory. During the first second of this flight, a foreign object intersected ScubeR’s path and appeared to make contact with ScubeR’s front guide handle. This unintentional change in momentum would cause ScubeR to trip over itself, and begin tumbling in circular motion. Upon further examination, the forgein object was hypothesized to be the robotic arm of the Northwest Nazarene University team. The NNU team was contacted to aid in the video analysis, in which the team confirmed the proposed hypothesis.

Due to the circular motion of ScubeR, the yielded results were much more complicated to ascertain than the simple distance vs time to obtain acceleration calculations that the team had anticipated. Since ScubeR underwent rotational motion, the distance from the cameras increased at a constant rate, however since the initial knock was off the longitudinal axis, the rate at which ScubeR was tumbling was hypothesized to increase. In observing the frequency of ScubeR's rotation, the angular velocity was found to be gradually increasing. This suggests the existence of an angular acceleration which is supplying additional torque to ScubeR.

In further analysis, it was concluded that the center of mass of ScubeR was located just under the line of action for the thrust caused by sublimation. This small vertical component would have minimal effect in a straight deployment and was of no concern in experiment design. However, it is speculated that when the robotic arm caused ScubeR to execute circular motion, this vertical component would have a considerable effect on trajectory and needed to be considered.

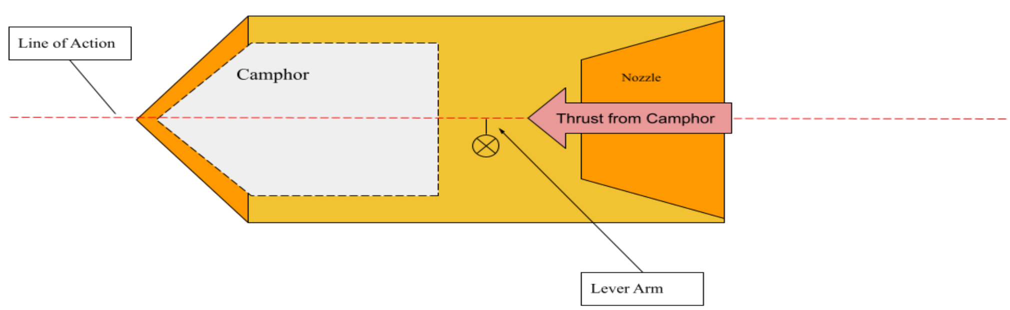


Figure 11.1. This diagram shows the visualization of the force acting upon ScubeR and its relation to the center of mass.

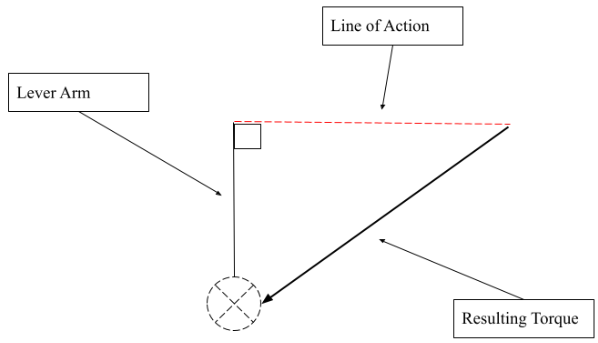


Figure 11.2. This diagram shows the resulting torque acting upon SubeR.

While ScubeR is undergoing a circular trajectory, the sublimation of Camphor is supplying a perpendicular force about the center of mass. This would cause a torque to act on ScubeR, and an overall increase in its angular velocity. In the general case, an off axis thrust would complicate these matters. However, it was observed that the translational velocity of ScubeR remained constant, which indicated any force acting on ScubeR would be affecting the rotational motion completely.

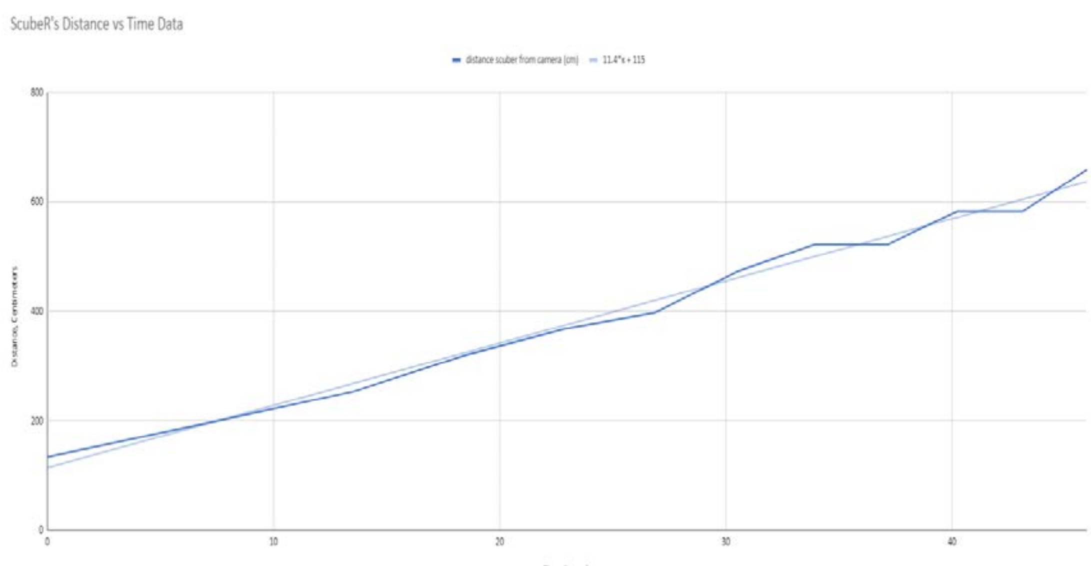


Figure 12. This graph shows the linear trend of the tangential velocity of ScubeR. As such, it can be concluded that any sublimation that is acting upon ScubeR is producing thrust that is directly transferred to the rotational component of ScubeR's trajectory and increasing angular velocity.

In knowing the change in ScubeR's frequency and its time, the angular acceleration can be calculated. Conjoining this with ScubeR's moment of inertia, the thrust caused by the sublimation of Camphor can be found.

$$T = \frac{2\pi I}{r_\perp}\frac{df}{dt}$$

The Specific Impulse of Camphor

Throughout the flight, ScubeR had maintained a rotational trajectory such that the cameras were perpendicular to the axis of rotation. Considering the bright orange color of ScubeR's nosecone and nozzle, this made frequency measurements convenient. With further analysis, ScubeR's frequency was calculated to be 0.01095 ± 0.23247 Hz with a correlation coefficient of R = 0.9891; indicating a strong positive correlation. The moment of inertia was calculated by considering the various parts of ScubeR: the nose cone, the Camphor, and the nozzle, as circular disks in addition to the fuselage. With ScubeR being mostly hollow, this methodology was determined to be a good approximation. In measuring the length of the proposed lever arm, in addition to the time interval in the change of frequency, the thrust supplied by the sublimation of Camphor was calculated to be $T = 527.6\mu N$.

The specific impulse of a material can be calculated by knowing its thrust and mass loss rate.

$$I_{sp} = \frac{T}{\dot{m}g}$$

Utilizing the mass loss rate of 1 gram per hour, the specific impulse of Camphor was calculated to be extremely high. The result proposed that Camphor outperformed the typical performance range of solids and was competing with the specific impulse of liquids. This result fell out of the ordinary and several considerations were made to adjust this conclusion to something more realistic.

Considering the hygroscopic nature of Camphor, it is hypothesized that while the Camphor was exposed to the atmosphere in the days leading up to launch, it could have retained water from the humidity of the environment. Knowing that the Camphor fuel would have been exposed to the atmosphere for the three days that it remained installed in the Improved Terrier-Malemute Rocket, it was concluded that the hydroscopic Camphor had retained trace amounts of water when ScubeR underwent its flight. The potentiality of water sublimation would be a considerable factor with regards to the mass loss rate.

In examining the temperature conditions of the environment and ScubeR's component material, PLS, various thermal considerations were taken into account. In doing so, the residual heat retained in ScubeR in addition to the proposed presence of water sublimation would substantially affect the mass loss rate of

ScubeR. Taking these factors into account, a more expected mass loss of rate of $2.41\frac{\mu kg}{s}$ was calculated, and early estimates for the specific impulse of Camphor was found to be 22.5 seconds.

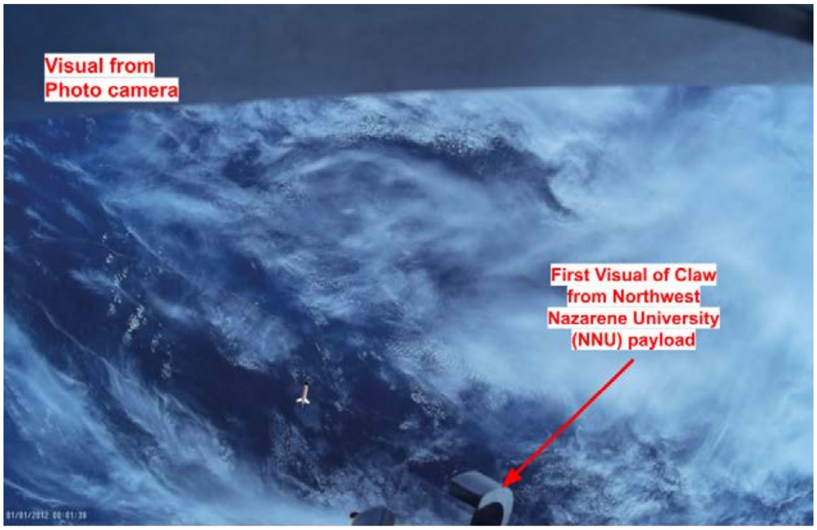


Figure 13.1.

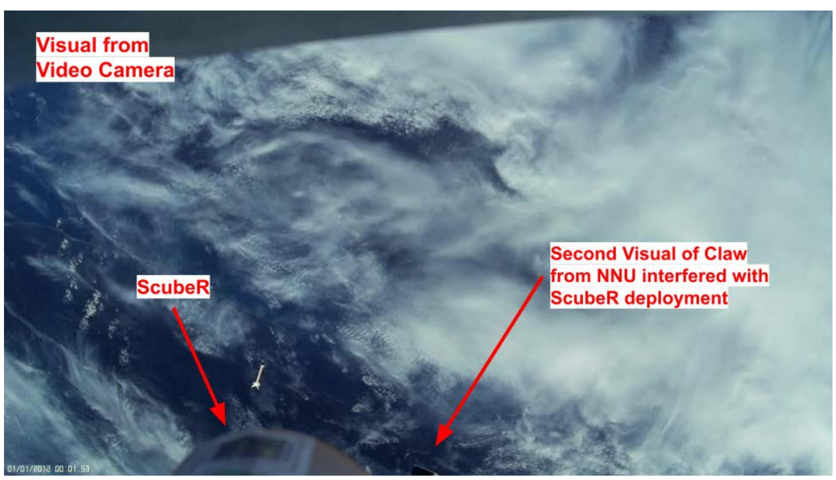


Figure 13.2.

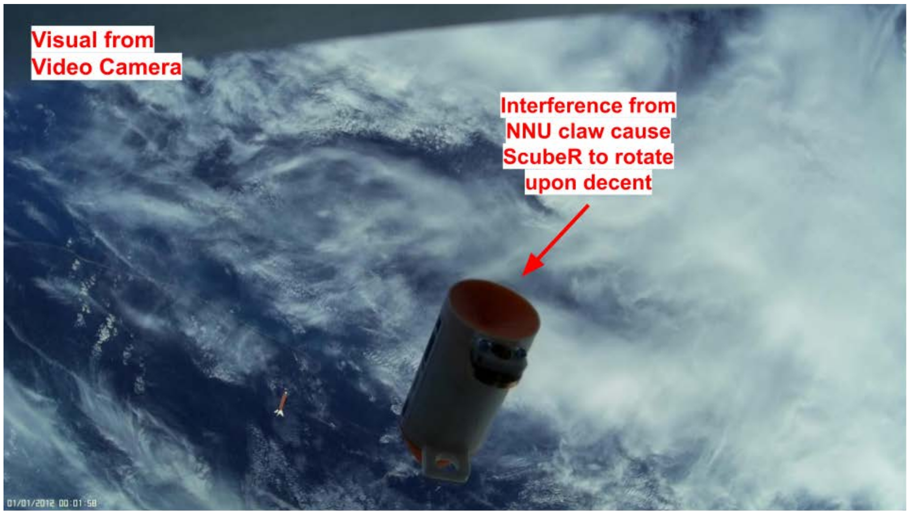


Figure 13.3.

Figure 13.4.

Data Controller

The data controller results reflected the expected thrust and flight path, but the device was positioned in the opposite direction of the rocket, so the data derived was flipped.

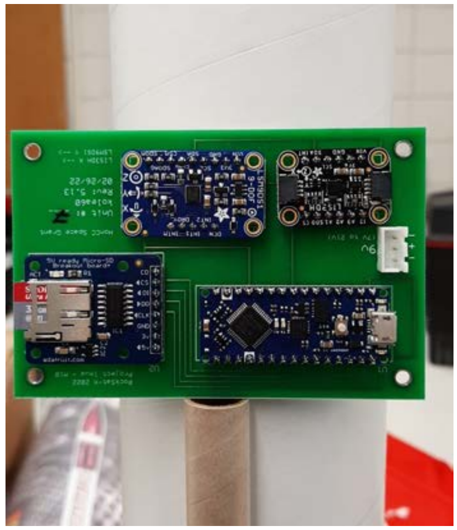
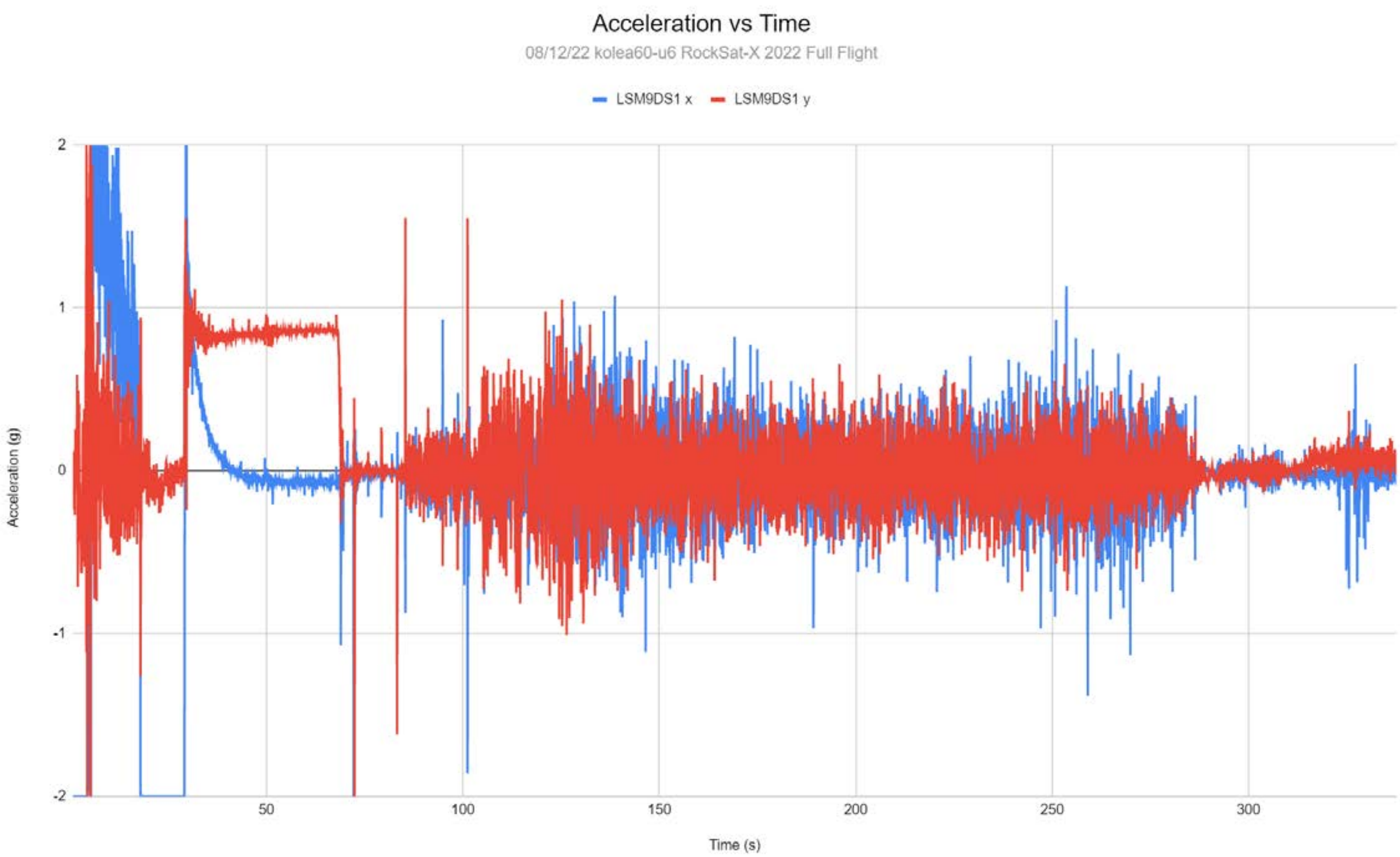
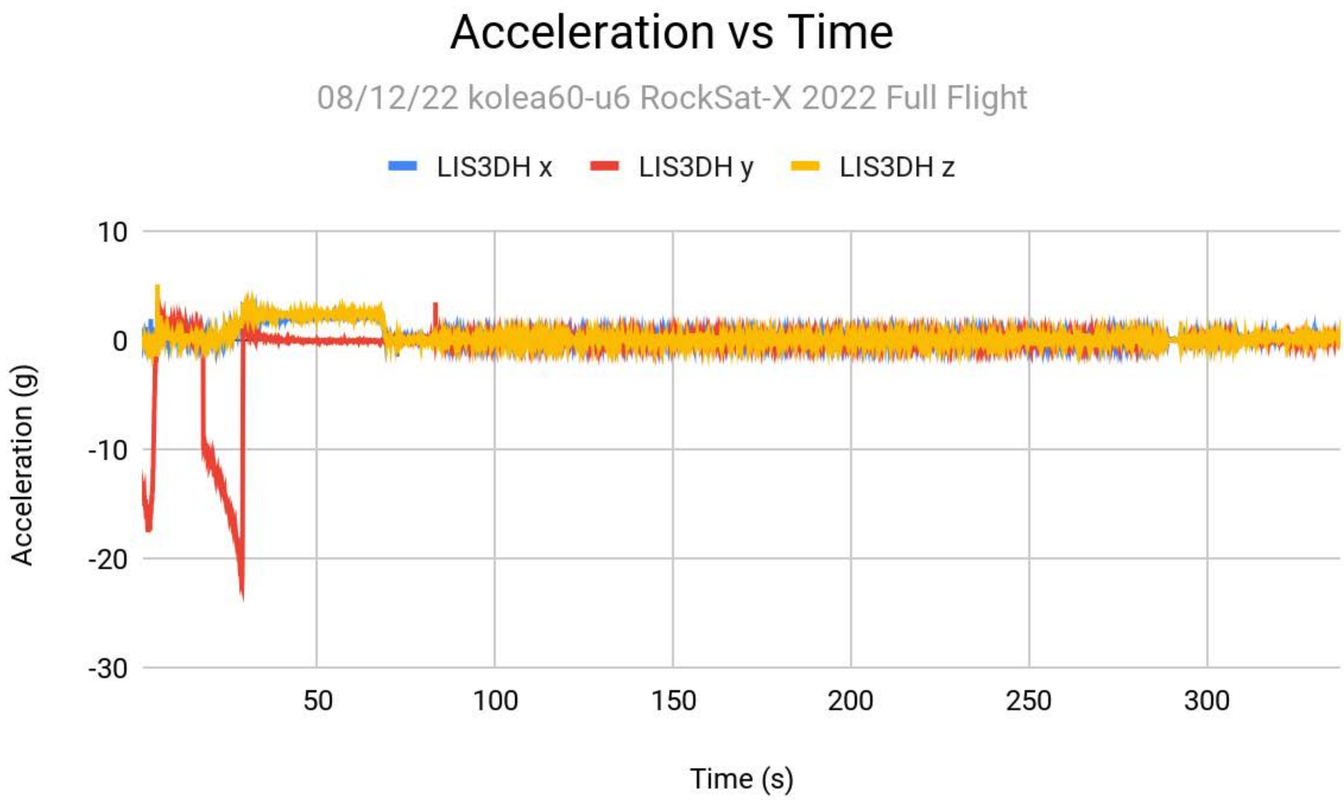


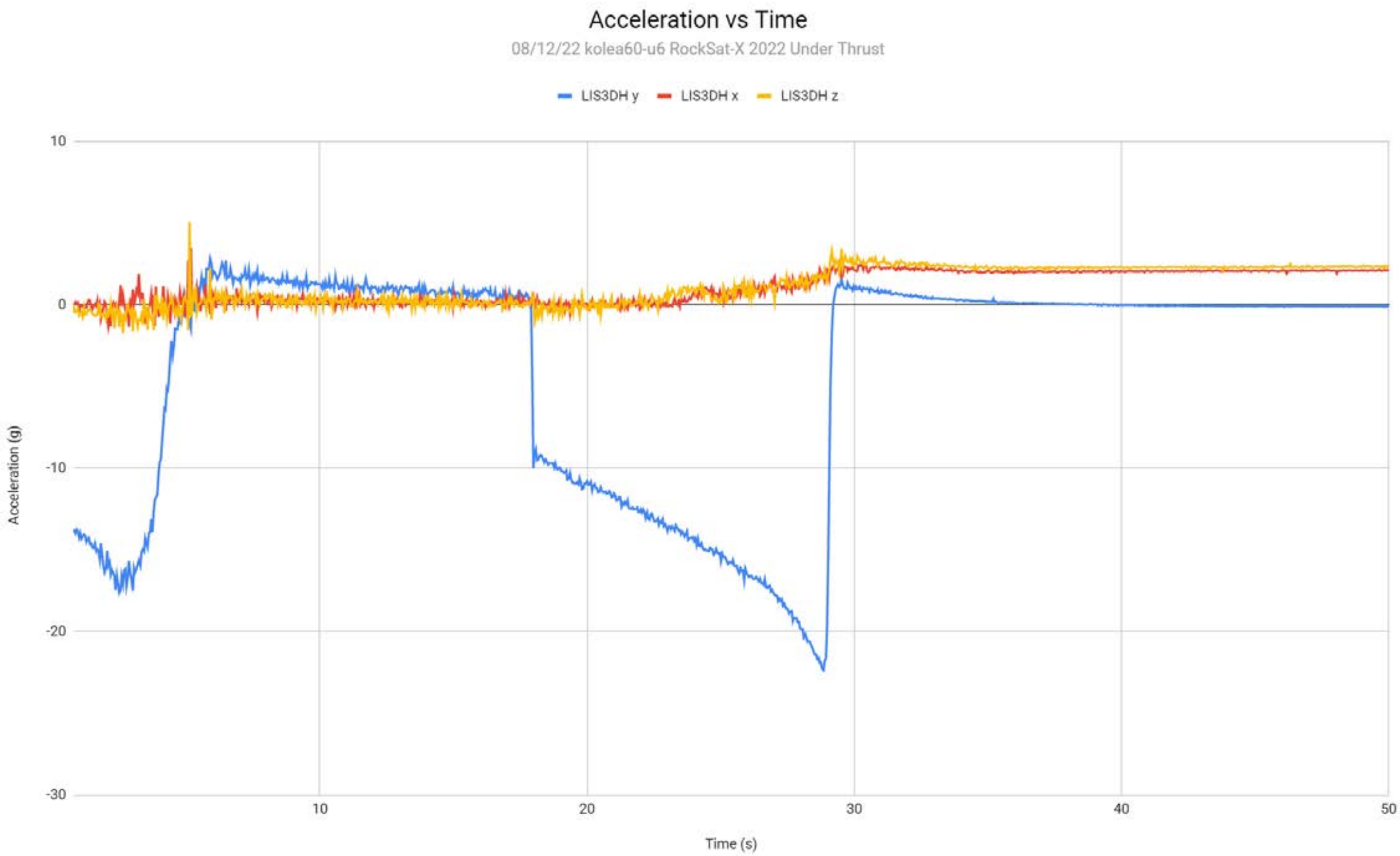
Figure 14. An image of the data controller.

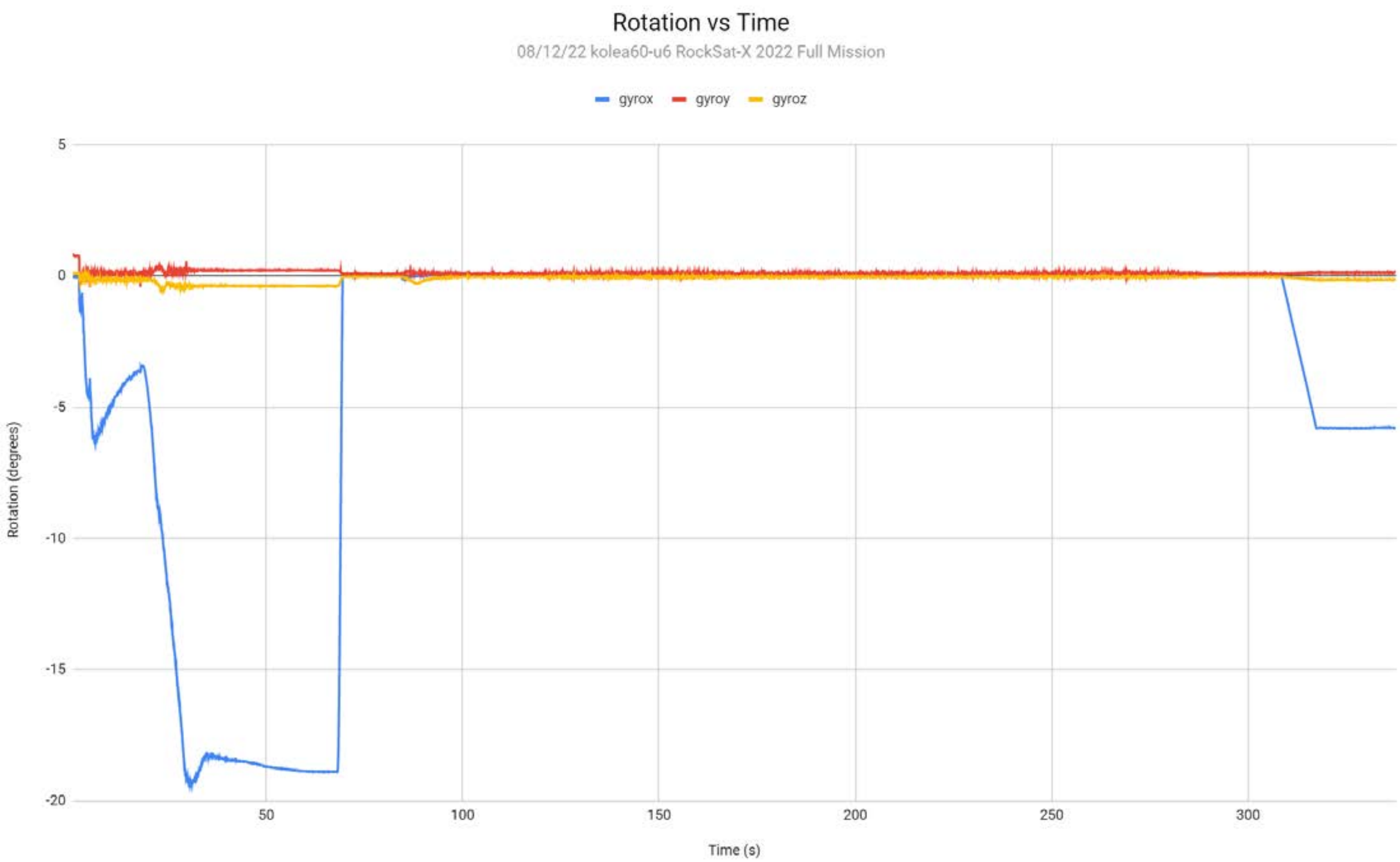
The interference from the other team's claw was first heard from the video at 93 seconds (1min 33s), the claw was visually seen at 95 seconds (1min 35s) and ScubeR was released around 109 seconds (1min 49s). The data from the IMU (LSM9DS1) accelerometer measuring ±2 g, showed spikes during the claw interference with ScubeR's release from 93s to 109s, but the spikes were not necessarily from the claw's interference. The data showed a negligible difference at 93s and only caught the spike around Scuber's release at 109s. In this case, the video camera was better at documenting any interference with ScubeR's release.

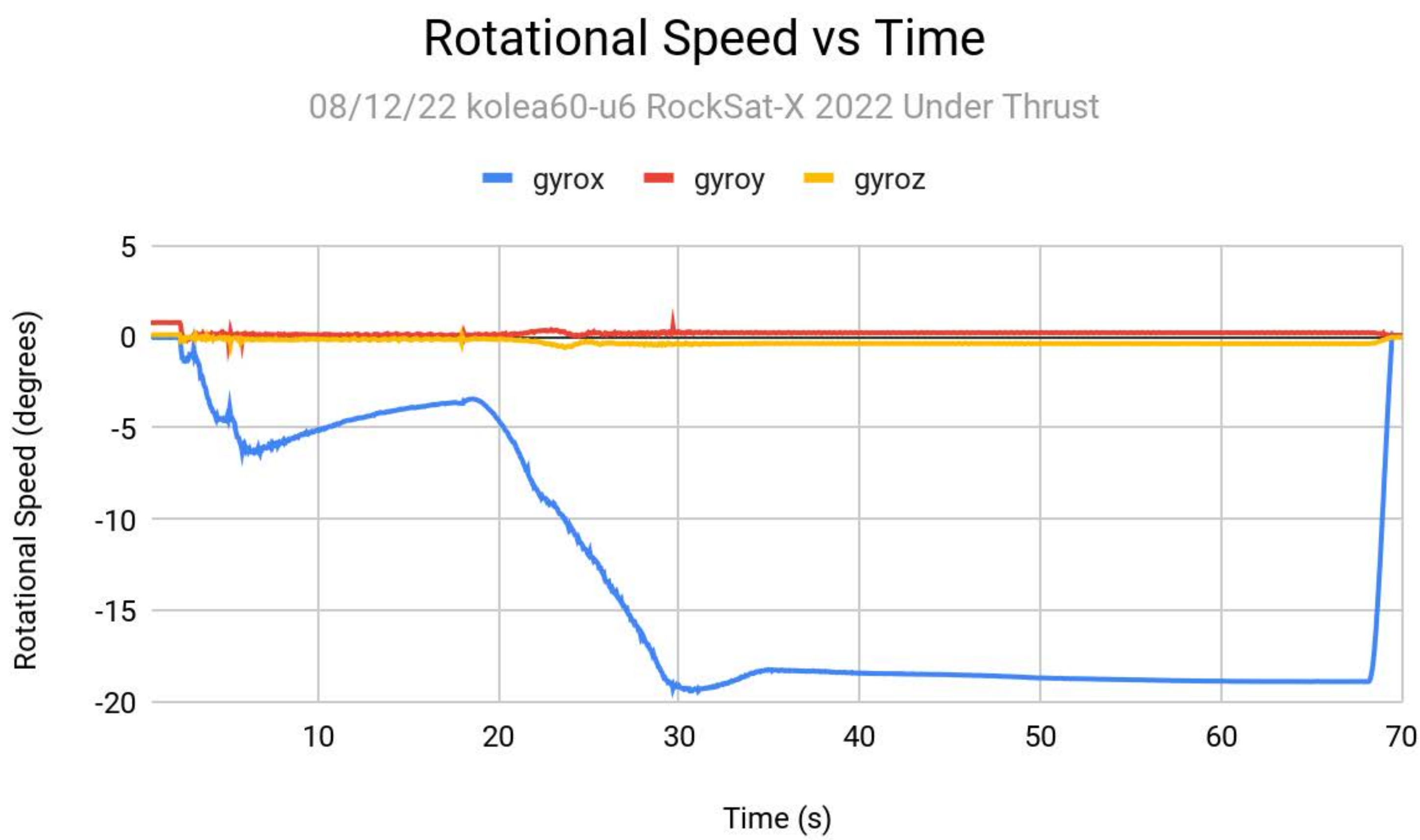

Acceleration vs Time
08/12/22 kolea60-u6 RockSat-X 2022 Full Flight
LSM9DS1 x
LSM9DS1 y
Acceleration (g)
Time (s)



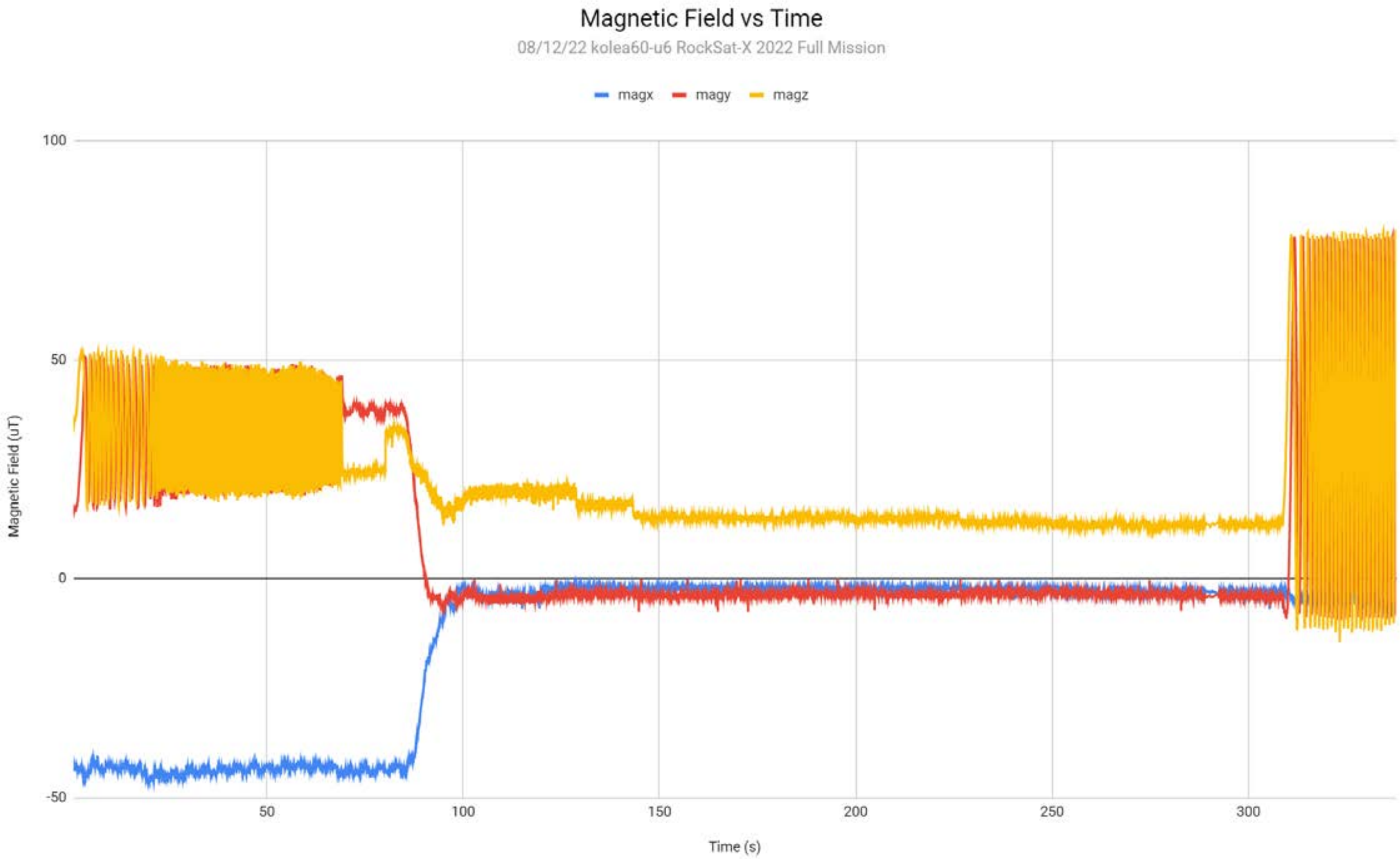
Acceleration vs Time
08/12/22 kolea60-u6 RockSat-X 2022 Full Flight
LIS3DH x
LIS3DH y
LIS3DH z
10
0
-10
-20
-30
Acceleration (g)
50
100
150
200
250
300
Time (s)


Acceleration vs Time
08/12/22 kolea60-u6 RockSat-X 2022 Under Thrust
LIS3DH y
LIS3DH x
LIS3DH z
10
0
-10
-20
-30
Acceleration (g)
10
20
30
40
50
Time (s)

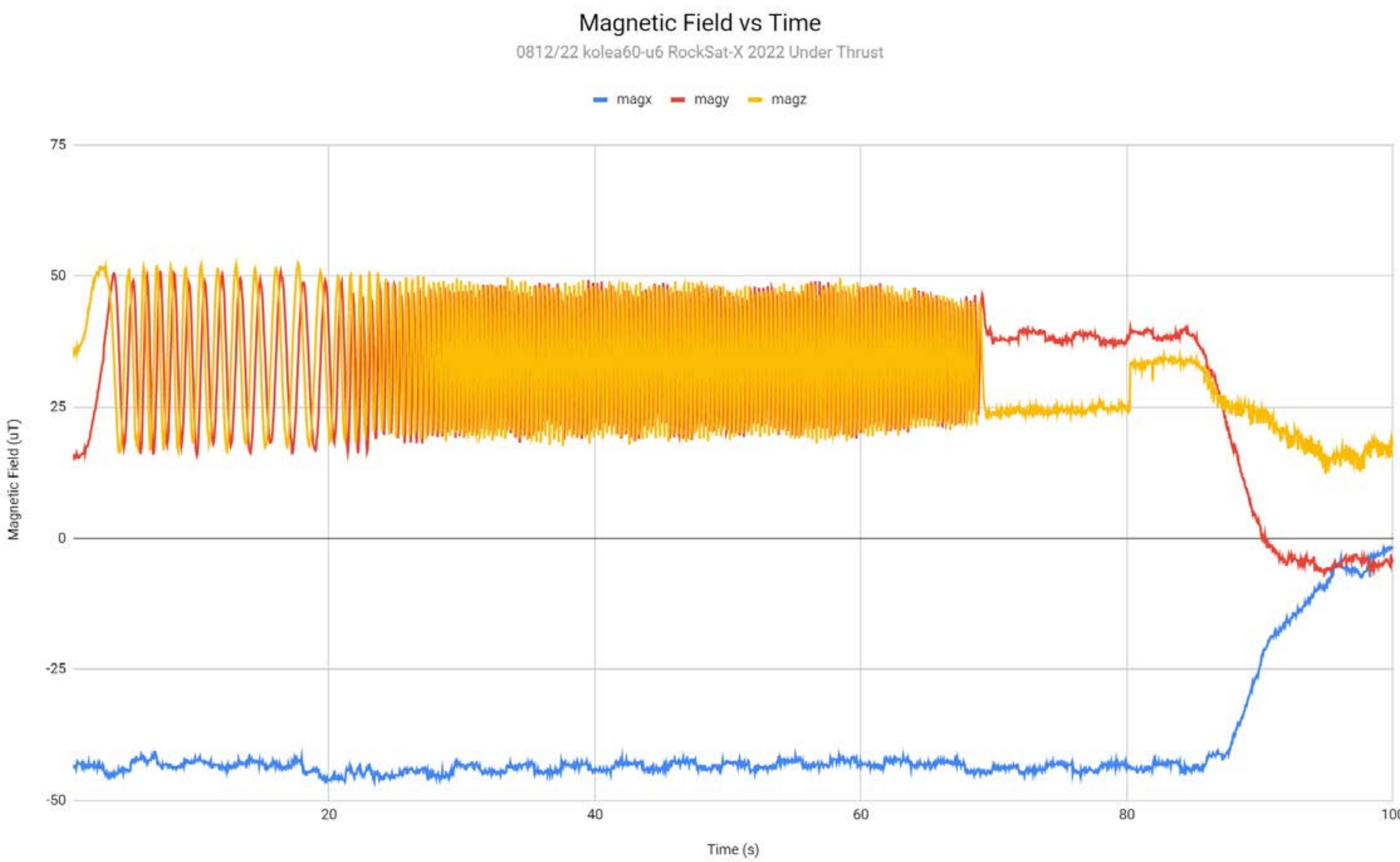

Rotation vs Time
08/12/22 kolea60-u6 RockSat-X 2022 Full Mission
gyrox
gyroy
gyroz
5
0
-5
-10
-15
-20
Rotation (degrees)
50
100
150
200
250
300
Time (s)



Rotational Speed vs Time
08/12/22 kolea60-u6 RockSat-X 2022 Under Thrust
gyrox
gyroy
gyroz
Rotational Speed (degrees)
5
0
-5
-10
-15
-20
10
20
30
40
50
60
70
Time (s)



Magnetic Field vs Time
08/12/22 kolea60-u6 RockSat-X 2022 Full Mission
magx
magy
magz
100
50
0
-50
Magnetic Field (uT)
50
100
150
200
250
300
Time (s)


Magnetic Field vs Time
0812/22 kolea60-u6 RockSat-X 2022 Under Thrust
magx
magy
magz
75
50
25
0
-25
-50
Magnetic Field (uT)
20
40
60
80
100
Time (s)

7.0 Conclusions

Conclusions drawn from the results showed that everything was working properly, and went according to plan; except for an unexpected interference from another team's payload. Due to this interference, an external torque acted on ScubeR which added a rotational component to it's trajectory. The cameras showed clear photos and video of ScubeR's release as well as the interference from another team's claw (both audibly and visually). The data controller showed that the flight went as expected. Additionally, the Artemis CubeSat had a successful proof of concept flight.

Despite the challenge of accounting for ScubeR's circular motion, the change in frequency of rotation was found which supported numerical calculation of Camphor's specific impulse. Taking some thermodynamic factors into account, in addition to the hygroscopic nature of the sublimate; the specific impulse of Camphor was found to be 22.5 seconds.

8.0 Potential Follow-on Work

The mission could be flown again with precautions set in place to deal with potential outside interference with ScubeRs release. Additional and more precise measurements aid in verifying these findings with additional direct measurements to compare against. Initial concepts of improvement involve total redesign of the sublimation rocket which would implement the measurement of the rotational rate due to a torque enacted by sublimation. This design is thought to mitigate any concerns of external torques. Additionally, other sources of sublimation can also be utilized to vary fuel sources for venier systems which broadens material availability and selection.

With regards to the Data Controller, an additional gyroscope could also be added in order to separate high from low rotations of the deck plate. Telemetry data could also be utilized to send data back to the ground station as a backup if SD cards got damaged upon re-entry. Additionally, by increasing the capture time of the onboard cameras from 30 fps to 60 fps could increase the timing accuracy of trajectory measurements.

Currently, the data collected during flight is still being analyzed and future investigation and supplemental data associated with the collaboration of the Northwest Nazarene University team is thought to lead to increased accuracy in data and failure analysis. Additionally, ongoing investigation may yield future publication dependent upon the success of this ongoing investigation.

9.0 Benefits to the Scientific Community

Investigating the specific impulse of Camphor aims to provide a better understanding of fuel sources for low thrust venier systems. Initial applications focus on the improvement of ACS and MMU systems for both rockets and astronauts respectively. Broadening potential fuel sources for these systems can yield greater variance in fuel choice and propagate competition which can reduce the cost of space access. By investigating sublimation as a means of propulsion, greater variance in venier systems is an additional benefit in both research and practical application.

Far-reaching applications of this research can extend to orbital companion drones which utilize sublimation as a means of propulsion to aid orbital construction and maintenance conducted by astronauts.

10.0 Lessons Learned

In early evaluations, the specific impulse of Camphor was derived and the operation of all subsystems were successful. Camphor has been found to be within its specific impulse range for solid sublimates and further research and application is promising.

ScubeR's Flight

Despite unexpected challenges occurring during ScubeR's flight, the mission objectives were able to be achieved. However, there was a loss in precision due to this unforeseen obstacle. Previous iterations of this experiment have been subjected to external torque which has caused data loss. As such, great care was taken to ensure a straight deployment of ScubeR during this experiment. While various mitigations can be implemented to ensure a strict series of events, adaptability and enginuity have been lessons that are paramount to the success of the experiment.

In consideration of the difficulty in avoiding external torques in conjunction with the methodology that was adapted to yield current results; it is thought that the experiment can be modified to produce a greater certainty in results at the exchange of additional mathematical rigor. Initial ideals of payload improvement keep the recording and image aspects, however; instead of utilizing a mathematically simplistic straight deployment of a sublimation rocket, ScubeR could be redesigned to produce a torque from sublimation. In doing so, the premeasured distance from the point of rotation and the experimentally observed frequency of oscillation could be utilized to produce an improved measurement of specific impulse while significantly reducing the risk of data loss due to trajectory interference.

Taking the success of the cameras into consideration, the greatest risk factor in this experiment is the mitigation of external torques. So in continued development and flight of a similar experiment, great emphasis will be placed on mitigating this risk. This is most prevalent in continued research into the redesign of ScubeR and its redefined performance.

Data Controller

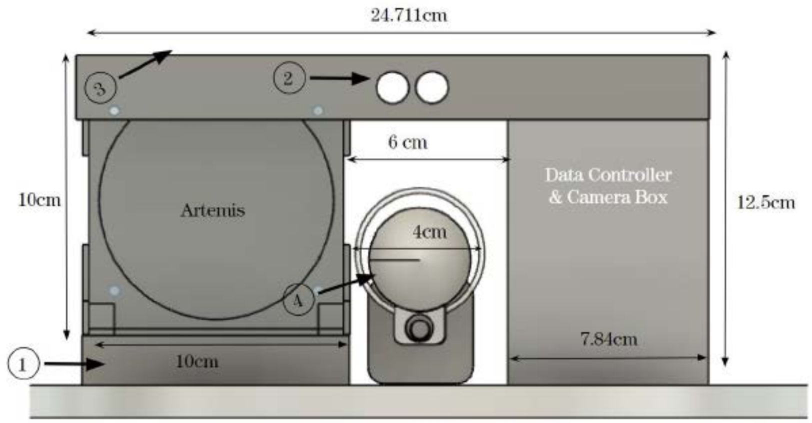
Instead of using the Adafruit Unified sensor library we should have used the raw data that the sensor comes out with, because there were discrepancies in the ranges that we set for the code and also complications with what measurement units the data was in; specifically the LIS3DH accelerometer that was set to ±16 g but the data went past 16 g.

The lower range accelerometer also could have been taken off, or positioned closer to the edge where the interference of ScubeR's release could be measured more accurately. This is because the low range ±2 g accelerometer data from the claw interference came out with negligible results compared to the cameras.

11.0 Appendices

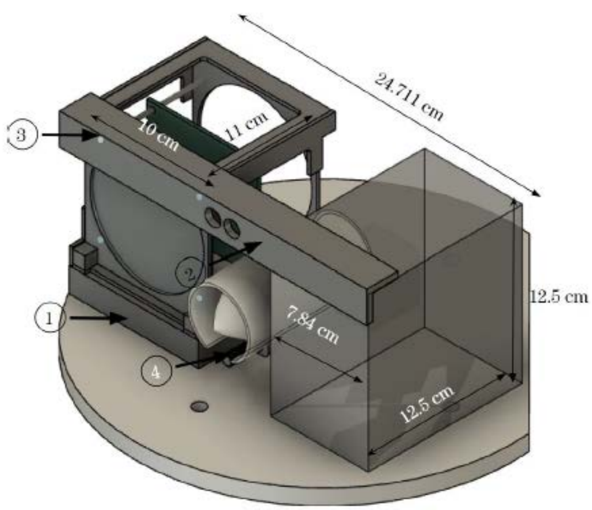
Appendix A

The plate shown in the designs is the actual deck plate minus the keep-out zone.



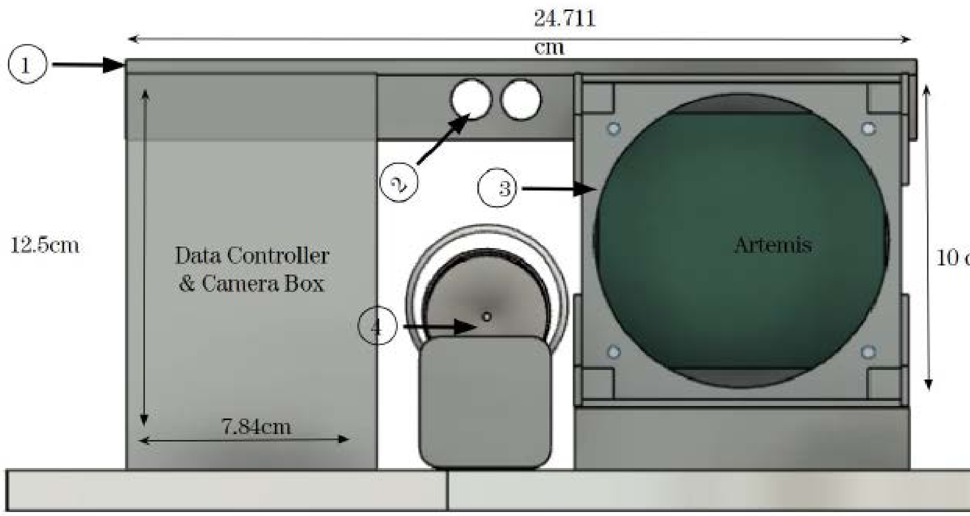
1. Dead Mass Base Plate
2. Camera Lensed
3. Lens Bridge
4. ScubeR Assembly

Note: ScubeR is a deployable sublimation rocket. Total deployment time is an estimated 14 seconds.

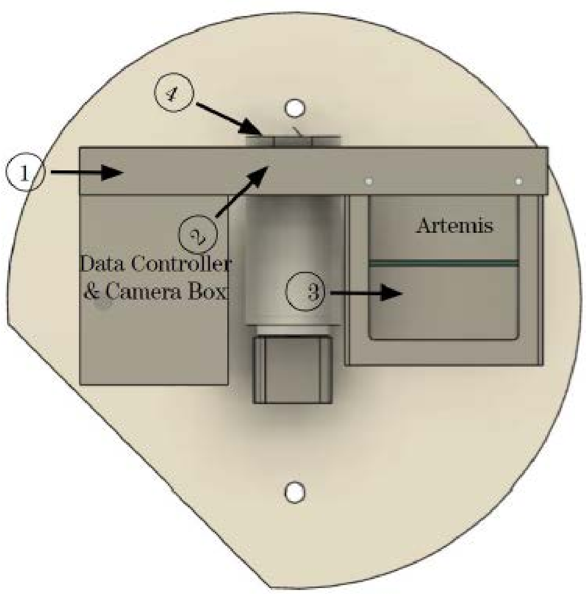


1. Dead Mass Base Plate
2. Camera Lenses
3. Lens Bridge
4. ScubeR Assembly

Appendix A.1.

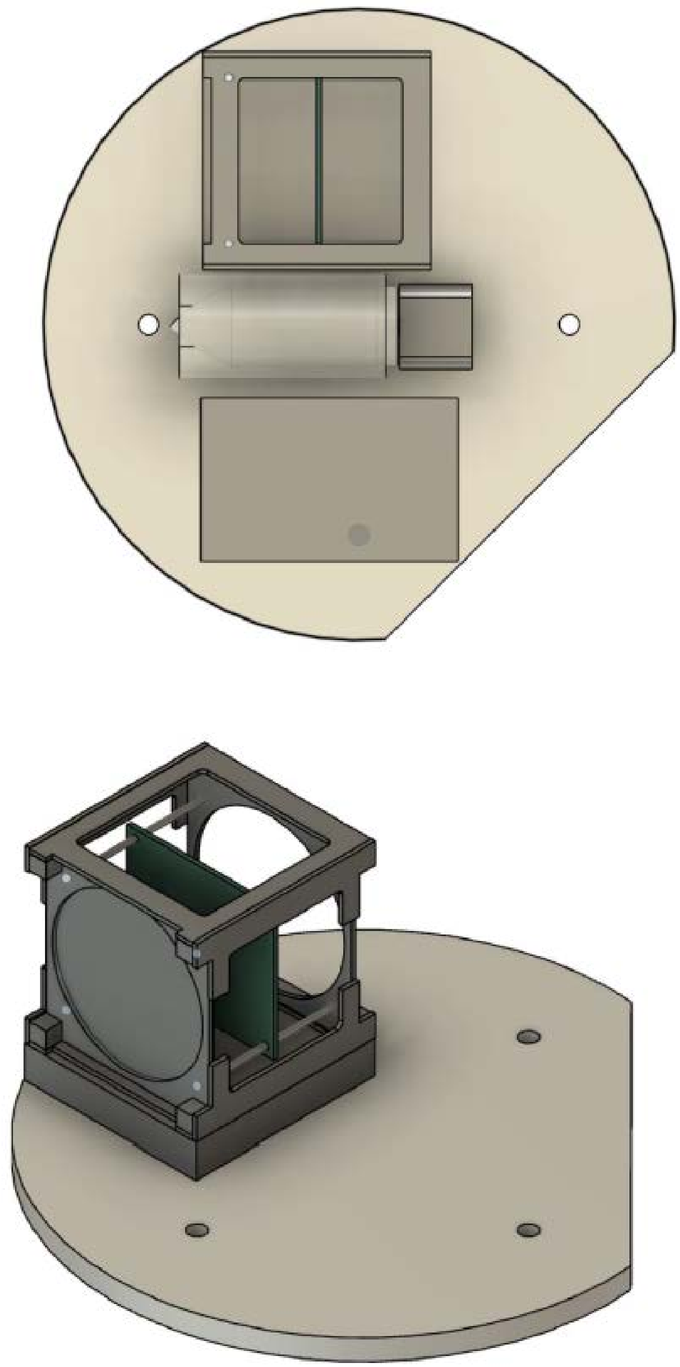


1. Lens Bridge
2. Camera Lenses
3. Artemis
4. ScubeR Assembly

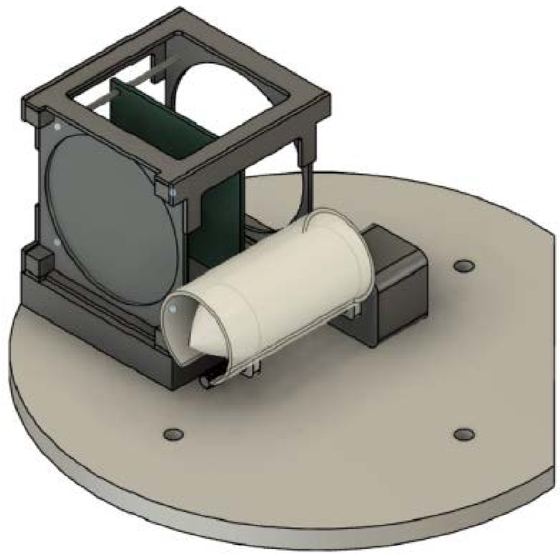


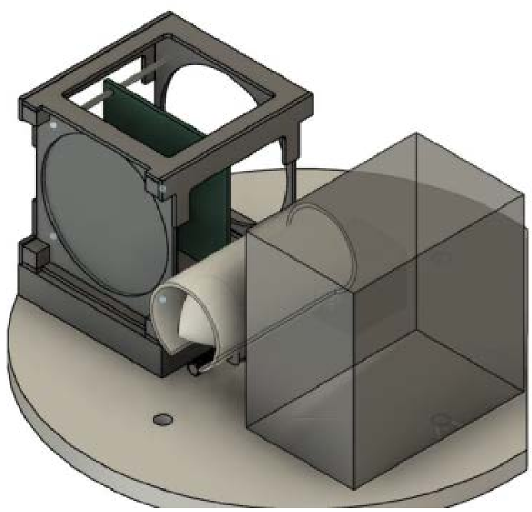
1. Lens Bridge
2. Camera Lenses
3. Artemis
4. ScubeR Assembly

Appendix A.2.



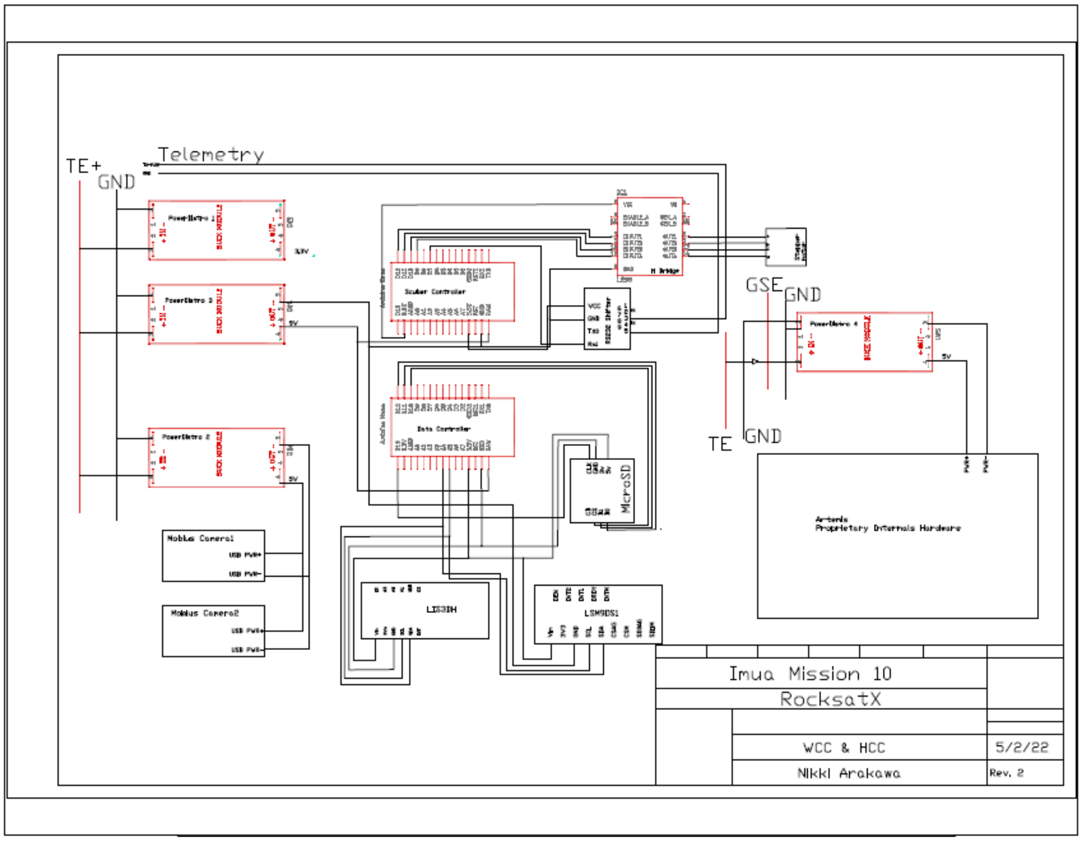
Appendix A.3.





Appendix A.4.

Appendix B



Appendix B.1. Electrical Diagram.