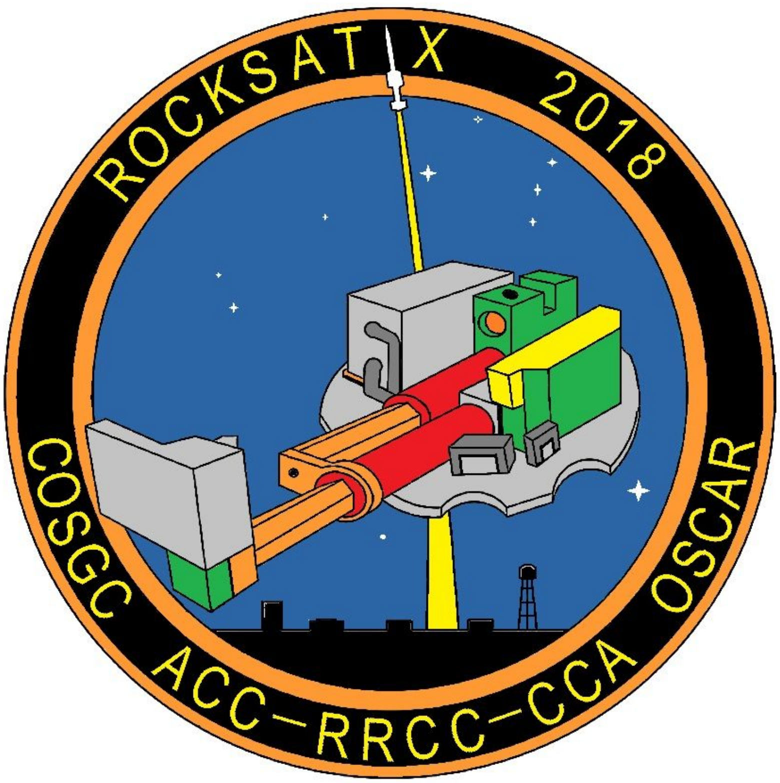
RockSat-X 2018 Final Report

O.S.C.A.R. (Orbital Scrap Collection and Reclamation)

Project O.S.C.A.R. aims to alter the trajectory of space debris during suborbital space flight, utilizing electrostatic fields to induce a dipole attraction in the debris.



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September 30th, 2018

1.0 Mission Statement

Project O.S.C.A.R. aims to successfully alter the trajectory of space debris during suborbital space flight, utilizing electrostatic fields to induce a dipole attraction in the debris. The fields will be generated mechanically and electronically, through the use of polyester material and by charging a parallel plate capacitor, respectfully.

O.S.C.A.R.'s goal is to see if these fields are a strong enough force to be able to influence the trajectory of debris. The pictures that will be stored and recovered will be used to calculate if the debris is visibly influenced by the fields. The small debris experiment will collect and use similar data via a second camera that will record video.

2.0 Mission Requirements and Description

Space debris has been and continues to be a growing problem due to the increase in space travel. In 1978 scientist Donald J. Kessler proposed a scenario where the density of objects orbiting in LEO becomes so high that an inevitable cascade of collisions occurs, where each additional collisions increases the likelihood of collisions in the future. This scenario is now known as the Kessler syndrome (La Vone, 2013).

O.S.C.A.R.'s mission is to perform a proof of concept experiment to confirm if using electrostatic force to alter the trajectory of space debris is a viable solution to the increase in high velocity small debris that makes for treacherous conditions for spacecraft and satellites.

The project's requirements were determined from our minimum and comprehensive success criteria.

Minimum Success Criteria:

- Data confirmation of debris change in velocity or acceleration of debris as a result of the charged material.
  - May include:
    - debris changing velocity after impact with the charged debris collector.
  - Failure would be the data showing no change in the movement of the debris.

Comprehensive Success Criteria

- Visual confirmation of the aluminum debris adhering to the capture device.
- Secondary experiment (Small debris Experiment) returns video data and shows a marked alteration of debris path, confirming experiment hypothesis.
- All pictures and data recovered for additional on-the-ground analysis.

To meet the above criteria and have a successful mission project O.S.C.A.R. created two main subsystems to meet the success criteria. The primary subsystem

was the boom arm, with the secondary smaller subsystem being the Small debris Collector.
The primary subsystem included the boom arm, which extended and retracted to allow the experiment a larger distance to be perform, a debris launcher that ejected debris to be collected, and a statically charged collector that was deployed from a box at the end of the boom arm, see figure 1.

The secondary system housed under the power converter box was a chamber of resin beads that were spun to gather charge and then place inside and electric field.

The two subsystems shared a common electrical system that provided power and recorded data.

In addition to the above requirements, the payload was also required to conform to all of Rocksat- X and Wallops Flight Facility user guide compliance. All compliances were met and a copy is provided in the appendix.

3.0 Payload Design

To meet the above criteria and have a successful mission project O.S.C.A.R. created four main subsystem teams to perform the research, designing, building, and testing before being integrated with the other subsystems. These subteams were materials, software, the Small Debris Collector, and mechanical which also included electrical.

The materials subsystem included the electrostatically charged collector hand and the interior of the collector box which charged the collector before extension. Materials subsystem also designed the electronics enclosure to be watertight for reentry. Software subsystem included the formatting and capturing of all images from the cameras. Software subsystem also investigated the use of OpenCV for image tracking but it was not used during the flight of this project. The Small Debris Collector subsystem consisted of the secondary smaller experiment which tested the triboelectric effect using resin beads and a capacitor. The mechanical and electrical subsystem included the extension and retraction of the boom, the design and printing of the 3D printed parts, choice of electronic components, wiring of all components, including utilizing a custom PCB and ensuring all other subsystems requirements were met to be integrated into the plate.

The majority of the components for the payload were 3D printed. This was primarily done because of budget restraints and a lack of access to shop equipment.

3.1 Payload Design: Materials

The materials subsystem conducted in depth research into the best material based on the triboelectric scale. Through this research it was determined that the best method would be to electrostatically charge the polyester by rubbing it against rabbit fur. This charged polyester will create a dipole-dipole attraction to the debris and the effect will be greater at apogee due to a vacuum.

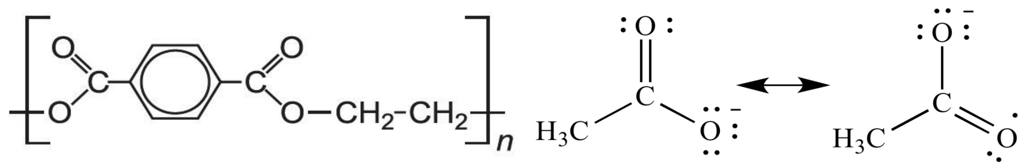


Figure : Dipole-dipole effect generated in the polyester

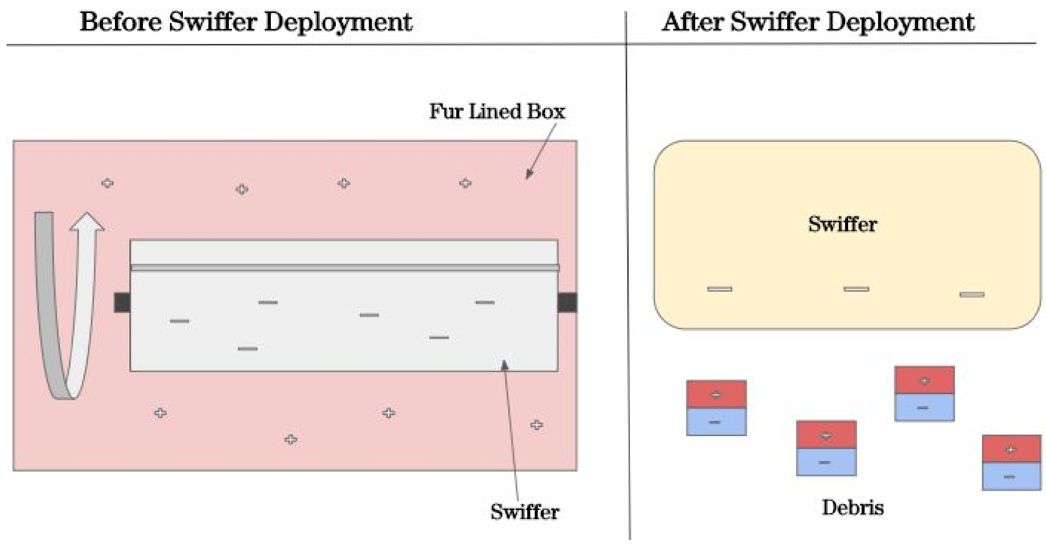


Figure : Electrostatic charging of the polyester

3.2 Payload Design: Software

Software design utilized the use of two Pi cameras to document each experiment. For the primary experiment a camera was aimed at the collector and took pictures every 0.5 second to mimic a video camera. This choice requires less processing, which helped the efficiency of the experiment. The design shown here included the use of OpenCV to track the debris inflight, however this software was not used during flight.

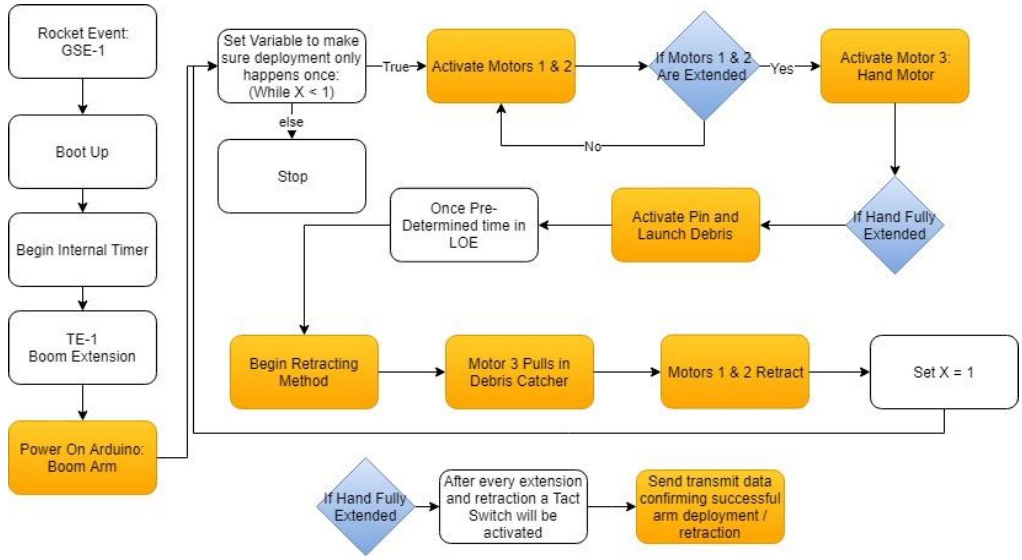


Figure : Software flow chart of main subsystem.

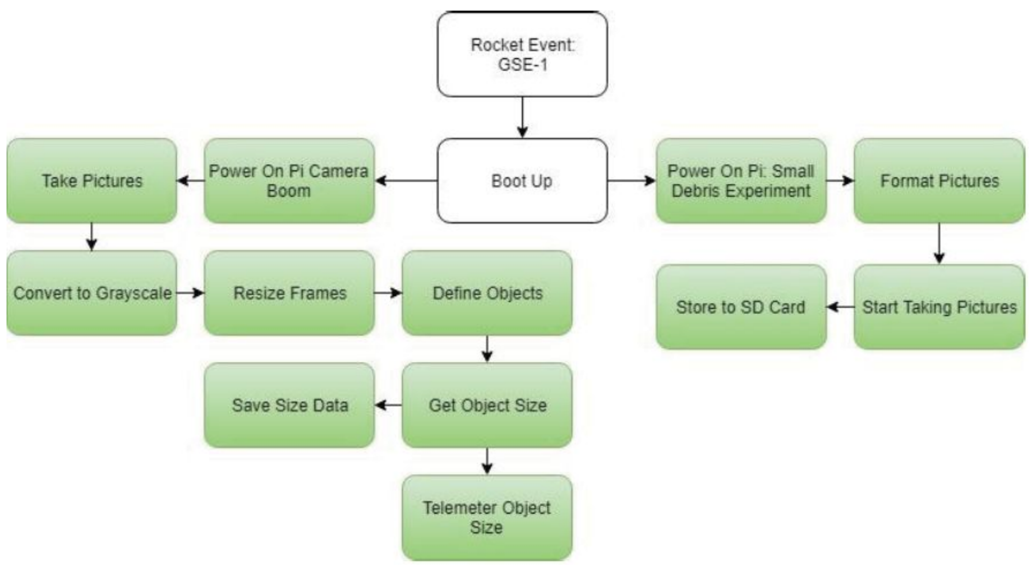


Figure : Software flow chart of Pi cameras.

3.3 Payload Design: Small Debris Collector

By maximizing space on the payload deck, an additional experiment, the Small Debris Collector, was created and flown. This experiment, which also tests the efficacy of electrostatic charge, is housed underneath the power converter box and uses resin beads and a parallel plate capacitor.

The resin beads were enclosed within a thin polypropylene tube attached to a motor which spin upon reaching apogee. The spinning straw was housed between two copper plates that charged, producing a capacitor.

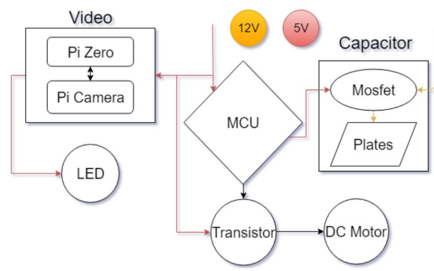


Figure : Functional block diagram for the Small debris Collector

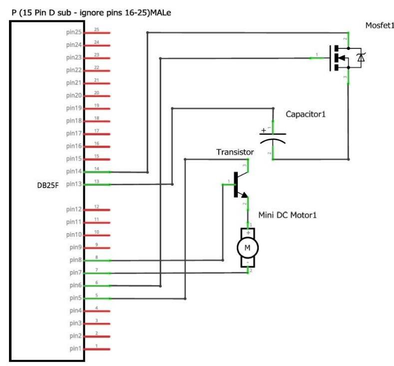


Figure :Wiring diagram for the Small debris Collector

The Small Debris Collector was designed to be illuminated from beneath with an LED and therefore had to be printed with clear ABS. Choosing to 3D print this part ensured the mounts for the copper plates, resin beads within the polypropylene tube, camera, and motor mounts fit within the constraints of the experiment, see figure . The base was covered with a custom 3D printed lid to contain this experiment.

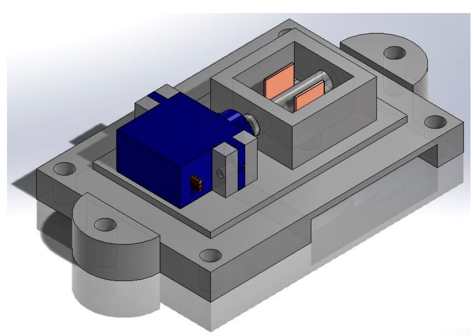


Figure : Base Plate of Small Debris Collector

3.4 Payload Design: Mechanical and Electrical

The design includes a two-stage boom extension possible through two nema-17 motors attached to acme screws that are able to “unscrew” the boom out, the second stage is required in order to obtain distance required from within the confined space requirements. The initial design would have used an arm to collect debris but was changed favoring simplicity and a more robust appendage. The second stage boom has a material box on the end which is charged, by friction, to attract debris such as aluminum pieces. Once the second boom extends, a small debris launcher located on top of the first boom, will deploy debris directed in the direction of the charged polyester material. A Raspberry pi camera also integrated in the arm will take pictures at a rapid frame rate to help determine if the charge was able to attract the debris. The cost savings and flexibility afforded to us by 3D printing a large part of our parts added an additional aspect of difficulty. With inherent issues associated with 3D printing, such as warpage and shrinkage during different stages of the process, but also allowed for quick turnaround when changes were made.

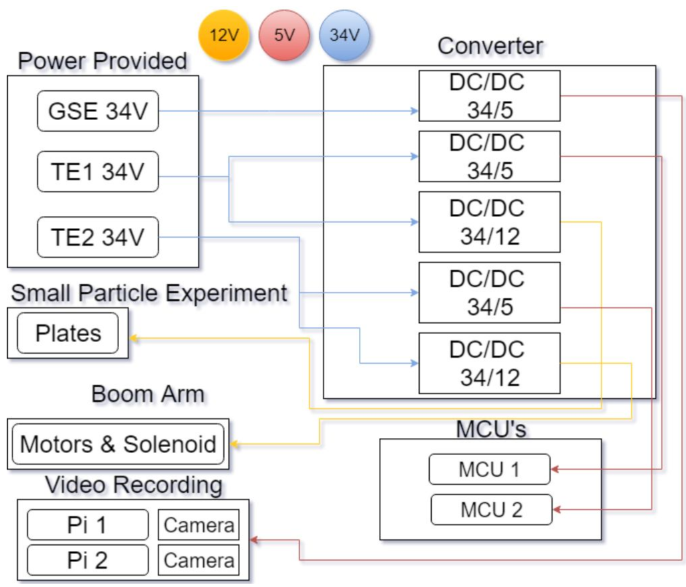


Figure : Functional Block Diagram for Power

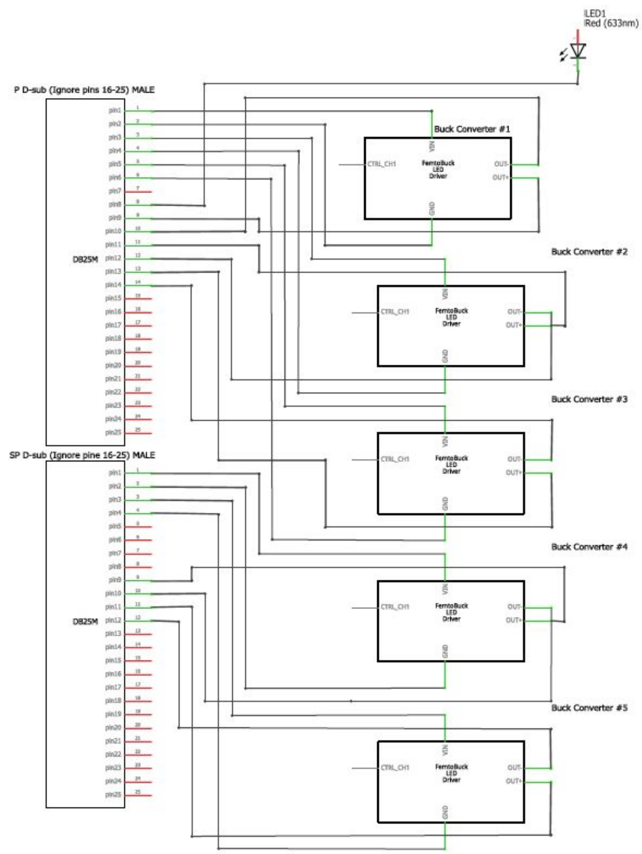


Figure : Electronics diagram for step-down converters

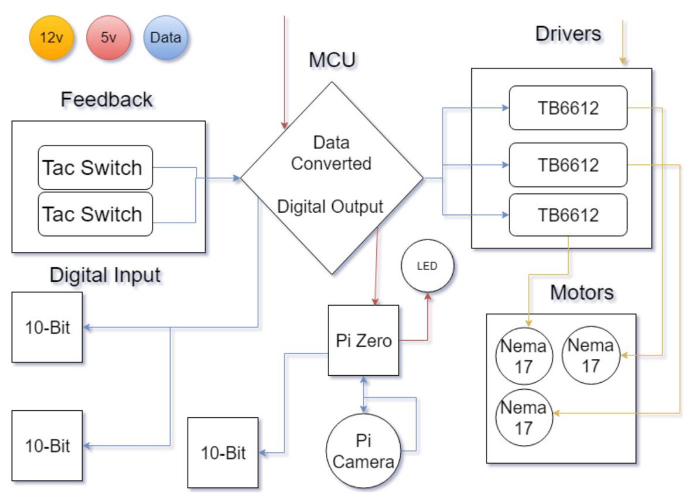


Figure : Functional Block Diagram for Boom Arm Extension

4.0 Student Involvement

Project O.S.C.A.R. was comprised of students from three community colleges, Arapahoe Community College, Community College of Aurora, and Red Rocks Community College, across the Denver metro area. The team was divided into four main subsystem teams; mechanical, Small Debris Experiment, software, and materials.

Student Roster:

- Erchis Erdenebat, Community College of Aurora, Mechanical Engineering
- Maggie Franchois, Arapahoe Community College, Environmental Engineering/ Applied Mathematics
- Rhiannon Larsen, Red Rocks Community College, Physics
- William Pfouts, Community College of Aurora, Mechanical Engineering
- Juvinni Pineda, Community College of Aurora, Mechanical Engineering
- Christian Prather, Red Rocks Community College, Computer Science
- Solomon Sidhu, Arapahoe Community College, Electrical/Computer Science
- Brianne Treffner, Red Rocks Community College, Engineering Physics
- Ashley Wolff, Community College of Aurora, Chemical Engineering
- Yilin Wu, Community College of Aurora, Chemical Engineering

Student Involvement		
Team	**Members**	**Team Role in Project**
Mechanical	Christian Prather, Brianne Treffner	Designed, built and tested mechanical elements including the boom arm, debris launcher, and power box. Designed and produced electronics system to provide power and collect data for entire payload. Including electronics wiring, custom PCBs and wire management for payload.
Small Debris Experiment	Maggie Franchois, Rhiannon Larsen	Researched, designed, and built the small debris experiment.
Software	Erchis Erdenebat, Juvinni Pineda, Solomon Sidhu	Programed the Pi cameras and researched the use of OpenCV for image tracking.
Materials	William Pfouts, Ashley Wolff, Yilin Wu	Researched science and material properties for electrostatic hand design. Researched and design electronics enclosure to prevent water damage during splashdown.

Figure : Team picture with payload after successful check-in

5.0 Testing Results

Due to the complexity of the system design and its subassemblies testing was critical to ensure all aspect and components worked together reliably at flight. The process of testing for reliability and functionality varies based on the subsystem however the criteria for success of reliability and durability remained constant through all.

5.1 Testing Results: Boom Arm

Due to the complexity of how our systems were integrated the testing process was critical. The team had to ensure that each subsystem was fully capable of functioning even in the harshest of conditions. One of the most critical was the boom itself. Being an early stage of the experiment timeline, the boom's mechanical reliability was at the foremost of importance. To ensure that the boom would extend and retract reliability the design first started by looking at proven systems such as the linear motion of 3D printer axes. Building off the acme screw and stepper motor design the booms mechanical motion was both accurate and easy to control with premade driver boards and Arduino libraries. Early tests included establishing appropriate timing of motor activation and experiments to ensure the system could linearly move and support the mass of the hand. Once the initial tests were completed and the system showed promising results of both controllability and power consumption the booms four major pieces were designed in SolidWorks and 3d printed in low density PLA (polylactic acid). Construction of the boom is when any design flaws were the most present, the initial few assemblies displayed issues with sizing as well as with tolerance between components. The mechanical team was able to sort these out with relative ease through repeated prints and only minor changes to the mechanical motion of the boom would be wanted for any future flight with the system.

The primary concern the team had with the boom prior to launch was its ability to handle the gravitational force of launch. To ensure the reliability of the booms individual 3d printed parts a force test was conducted. This involved the printing of a test part utilizing the exact material ABS (acrylonitrile butadiene styrene) at the density that would be flown. A force scale was placed in the center of the component and a force was applied exceeding that which was expected at launch. The printed component saw small levels of fatigue with small layer separation yet overall surpassed minimum success requirements.

5.2 Testing Results: Debris Launcher

The debris launcher was a very critical component in the experiment system as its success or failure decided if there would be data to analyze on ground. As such, the subsystem went through multiple test and redesign cycles; the primary concern being that the debris would be able to reliably be ejected at a given time. This proved difficult to confirm system success as the debris ability to travel depends on the microgravity environment they were exposed to. The team started with a conceptual design utilizing a compression spring and solenoid for activation. The initial test was successful allowing for a release of all debris . However, it was discovered during this process that the solenoid was not powerful enough to trigger the spring's release. The eventual switch to a micro DC motor geared up in a micro servo enclosure proved to offer the appropriate amount of torque needed. Once the reliable release of debris was established attention turned to the storage of material at launch. A system was needed to allow for safe containment of the debris throughout the rough conditions of launch. To accomplish this a lid was designed and attached to the booms end with high tension fishing line. The system was then tested on a shake table to ensure the consistent opening of the debris door.

5.3 Small Debris Experiment

Before a design for the small debris experiment was finalized, multiple prototypes were constructed to make sure the design was as scientifically sound as possible, as well as feasible to build with materials that were easy to access.

When the concept for an experiment that involved utilizing and observing the effects of electrostatic fields was decided on, the criteria for the design of such an experiment was that it could generate an electric field that was easy to observe, could produce results that could be replicated and compared to results obtained on Earth, and could produce dramatically different results when performed in a vacuum with the minimal effects of gravity. The design would also need to generate an electric field in a way that differed from the primary experiment. The decision to generate an electric field electronically instead of using the triboelectric effect meant that the results that were obtained would be easier to

replicate and quantify.
Initial prototypes involved generating a field using a concept similar to a Van de Graff generator, but because the static effects of such a device would be unpredictable, difficult to control and measure, and would use a lot of current, it was decided that the experiment could be modeled on a parallel plate capacitor by placing a 12-volt charge imbalance across two copper plates. Copper was chosen because it is highly conductive and is readily available. Early tests included hooking up two pieces of copper up to positive and negative nodes of a power supply and placing different materials between them from the triboelectric series, such as pieces of paper, aluminum, salt, plastic, and rabbit fur. Though the charged plates had little effect on any of these materials, it was illustrated through one particular experiment where resin beads was placed on a balloon that was rubbed with rabbit fur, that these small pieces of charged material reacted to the charged plates when they were placed near the materials that were stuck to the balloon. It was decided that in order for the parallel plate configuration to have any chance of working, materials which were already charged would need to be placed between the plates instead of trying to polarize materials using an electric field alone. Due to the power budget allotted for this experiment, it was apparent that it wasn't possible to simultaneously charge a material while maintaining a charge across the plates due to the large amount of current it would use. The material that was chosen would need not only a positive or negative net charge, but would need to maintain that charge by not discharging easily. Resin beads that were formerly part of a reverse-osmosis water filter experiment at Red Rocks Community College were chosen as the material to be placed between the plates. These beads were of reasonably consistent size and shape, and maintained their charge when handled. As for how these beads would be contained and observed, while also considering that the experiment would need to be small-scale, it was a challenge to find a material that was both transparent enough to enable observation but would also be thin enough to minimize the dielectric effect of the electric field generated between the plates. After deciding that any commercially available plastic tubing would be too thick and failing to find a glass container that was small and thin enough for the scale of the experiment, a transparent plastic drinking straw was chosen, being readily available, transparent, and thin.
Once we were aware of the parameters as far as the amount of amperage we were allotted, we were able to construct an experiment that we could expect to work and produce noticeable results in space conditions.
Once the basic physical design was finalized, multiple 3D printed prototypes were made, each being tested and altered as needed. The prototypes were printed using transparent material, which enabled the experiment to be backlit, and preventing the possibility of glare on the plastic cylinder obstructing the view of the experiment. After the 3D printed prototype was considered acceptable, the subsystem as a whole was tested, including camera configuration and focusing, reliable data storage, and finalizing of a time sequence for the events of the experiment.

5.4 3D Printed ABS Material

The majority of the payload was 3D printed using ABS as the filament. We decided to go with this material as it offered a high heat resistance and durability. Qualities that we needed for the payload to prevent warping and melting prior to flight; being that the rocket would be outside in the middle of summer in Virginia, which is not an ideal environment for plastics. ABS did present several complications with printing the parts. It was very temperamental towards any draft or other outside factors that encountered it during the print. This would cause almost all of the prints to warp slightly. After many trial and error prints we were provided an opportunity to use a better quality printer thanks to Red Rocks Community College. With the new printer we had better supports that were printed with each print and finally got 3D prints that were not warped. The other downside to using the ABS as a filament is the health concern associated with it. It adds an extra hurdle to jump over since you need to print in a well ventilated room, and preferably during a time when no one will need to go into the room until the print is done. Luckily, this issue was never too much of an inconvenience. Going into the design of using 3D printed parts we fully expected our payload to return as a big melted blob. We knew that the return temperature would get too high for the ABS to survive reentry. To our surprise however, the

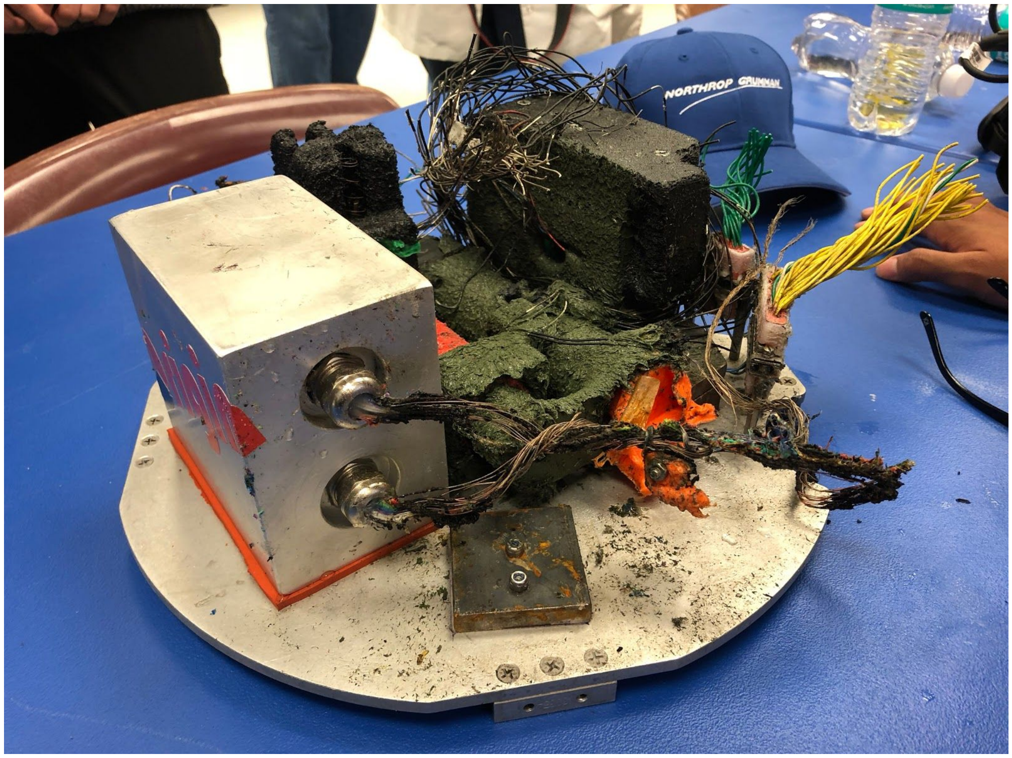


fig 5.1

payload came back way more in tact than we ever expected (see fig 5.1). While there is obvious heat damage and the payload is not salvageable, you are still able to make out what each component is. The main factor that we believe could have contributed to our payload not completely melting as expected is that our payload was the first payload in the series. Therefore, the upper half of the rocket would have shielded our payload from some of the reentry heat. We were very impressed with the performance of the ABS and would highly recommend it to future teams that have a limited budget.

6.0 Mission Results

Over all the mission was a success, all the minimum requirements for a successful mission outcome was met. From the images gathered, the boom deployed and retracted correctly. The Small Debris Experiment worked as intended and gathered data from it.

6.1 Mission Results: Boom and Components

For the boom section of the payload, it consist of two dependent components, the hand and the debris launcher. The hand is the piece that is connected to the end of the extending boom, and it houses the electrostatic material along with the camera to record it. The debris launcher is the component that sits stationary at the other end of the boom and is tasked with deploying the projectiles towards the hand. The debris are held in tacked by a cover that is connected to the boom, so that when it extends the debris are free to be launched. The boom itself is tasked with extending out of the payload boundaries for the experiment to be conducted.

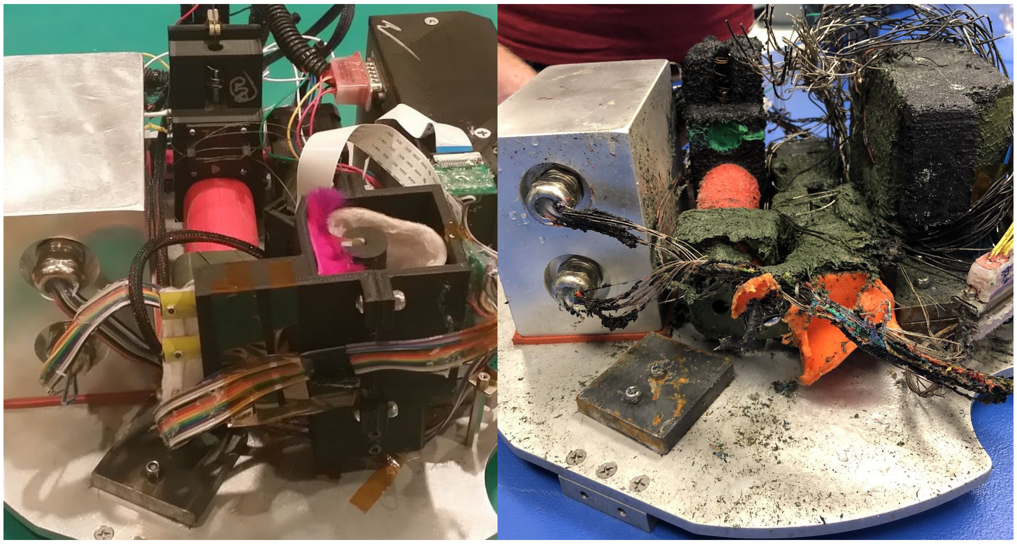


Figure 6.1

Upon seeing the stacks of payload retrieved from the ocean, the most notable aspects of the payload could be seen. A plethora of stranded wire was stretching across the payload to a dangling strands. It was noted upon closer inspection that the object was the melted remnants of the stranded wires that connected the camera on the hand component to the electronics box. From how the ABS bracket that held the motors for the hand deformed, it seemed like the hand component was ripped off when it was entering atmosphere. From figure 6.1 the extent of the damage to the hand component can be seen with a before and after image of the boom and its components. The damage received to the payload was expected, but the expectation on how well the ABS components resisted the reentry was surprising. The orange ABS bracket that held the hand with its motor, had completely melted off. The spring that launched the projectiles towards the hand was melted and fused with the housing of the debris launcher. From figure 6.1, the debris launcher is the very far black component next to the metal electronics housing. These two components (debri launcher and hand) of the boom seemed to have melted off first and the boom itself followed afterwards. The debris launcher worked because the bracket that stops the debris from flying away was gone and the spring had been triggered. Figure 6.2 shows a before and after image of the back of the debris launcher. From it, the blue servo motor that controlled the derbi launcher with its little PCB was completely melted off.

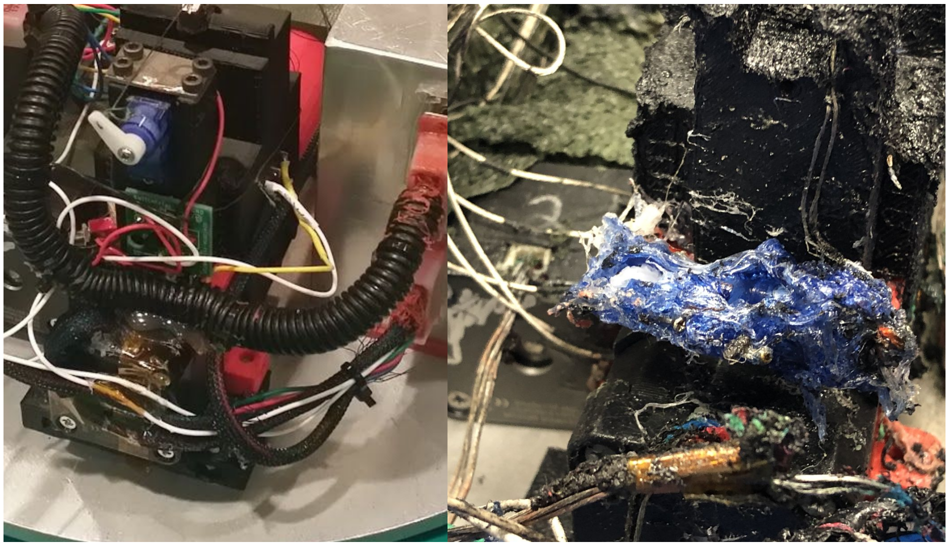


Figure 6.2

The most notable aspects of the boom and its components was how the ABS reacted to melting as it was heated on reentry. It seemed like the ABS was heated

Figure 6.3

and went under a rapid cooling. This suggest that the ABS was still hot or still melting as the whole payload was being lowered by the parachute and cooled fast when it splashed down.

Figure 6.3 shows a more detailed image of the melted textures of boom and debri components. The rapid cooling of the ABS makes for this interesting textures.

From the data collected on the raspberry pi, the question whether the debri launched correctly is still unclear. The images received from the payload show faint metal fragments that are floating away from the payload right when the boom arm extended outwards. Since the cover that protects the debris are connected to the boom by series of wires, the debris might have followed the extending boom outwards and passed the field of view of the camera. During this time, one component did not work properly. The hand component should have extended outward and created a place to catch the debris. It was noted that the motor that control the hand experiment did not function properly during the final sequence testing on the ground. This could have been due to an improper loading of the swiffer material and might have burned out the motor that was tasked with moving the charged material.

As it is seen from the series of figures. None of the debris that traveled from the chamber of the launcher reached the field of view of the swiffer experiment.

Figure 6.4

Figure 6.5

Figure 6.6

Figure 6.7

Figure 6.8

Figure 6.9

The figures from 6.4 to 6.9 show the only viable images of the unknown metal components that are floating in space and it also show the metal bracket that hold the payload in, as the boom arm extend outward. These sequences of picture are time stamped from +168 to +173 seconds after the GSE.

6.2 Mission Results: Small Debris Experiment

The Small Debris Experiment (SDE) functioned effectively during the mission and video of the experiment was recorded and retrieved. The Raspberry Pi replacement camera that was installed after correcting a cable malfunction was not properly focused. However, usable video data was still retrieved and analyzed. The LED adequately backlit the debris chamber, the DC motor redistributed the the debris beads, and the capacitor plates were charged with 12V of converted power from the GSE line. The camera recorded at 30 fps (frames per second) for 144 seconds. The video captured the Small Debris Experiment at apogee, from 14 seconds before the payload was fully despun and visibly experienced microgravity, until the payload began to descend. The DC motor and the capacitor plates turned on in sequence with Timer Event 2, as planned. The capacitor plates were charged while the DC motor spun, physically redistributing the resin debris beads within their cylindrical chamber. The plates were charged and beads were spun simultaneously while the payload was in microgravity.

Before the charging commenced, the beads floated briefly in microgravity, (see figure 1), then the chamber was spun for 36 seconds, (see figures 2 and 3). After the spinning ceased, the beads displayed clear attraction to the polypropylene walls of the chamber, (see figure 4). There was a noticeable concentration of beads near the bottom plate, the negatively charged plate, while the top (positive) plate was nearly free of beads. Instead, beads had accumulated in a clump just beyond the edge of the plate. It is hypothesized this occurred due to repulsion from the positive plate, since the beads had been charged positive in previous testing sessions. After the debris distribution completed, three beads traversed the chamber toward the highest concentration of beads at the bottom of the video frame. The final image illustrates the bead’s response to descent, (see figure 4). The following images illustrate these observations. The time sequence can be used to better interpret the images, see table .

Photo Edit	Indication
Green Lines	Outer bounds of Chamber
Orange Lines	Capacitor Plates; Bottom (-), Top (+)
Blue Area	Shadow present from background objects

Table : Key for Images

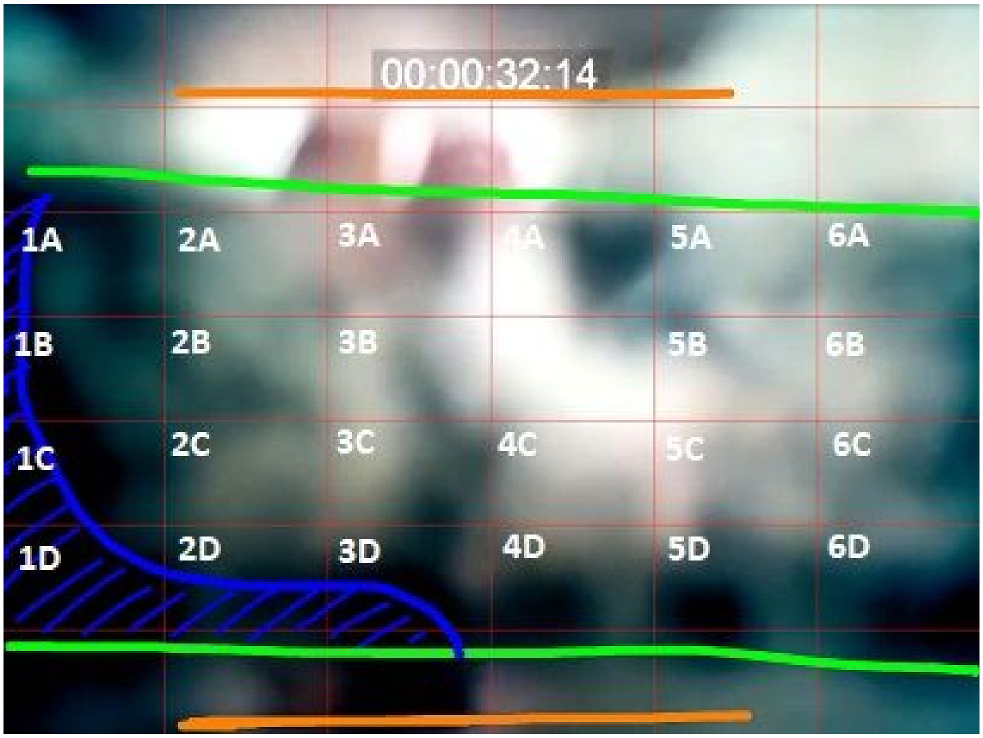


Figure 1: (t = 202 seconds) Uniform disbursement of debris beads throughout the chamber in microgravity.

Figure 2: (t = 253 seconds) Shortly after TE2 is activated, beginning of spin cycle with the capacitor plates powered, beads in motion darken the entire chamber.

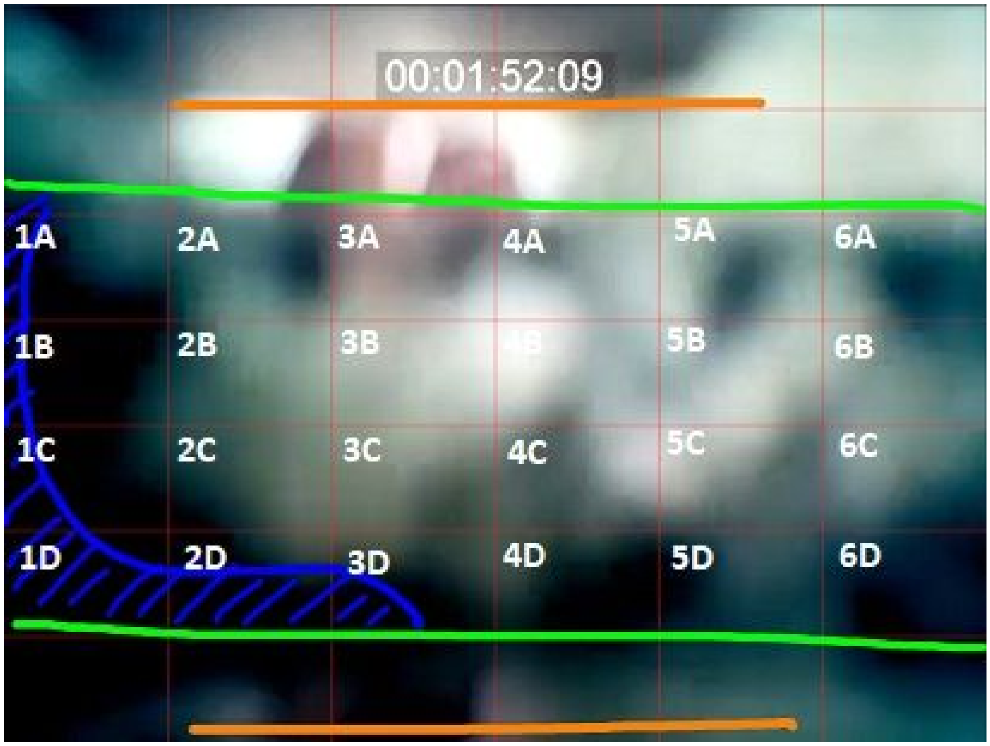


Figure 3: (t = 282 seconds) End of the spin cycle, beads are static charged and clumping. Beads are gathering in Row D.

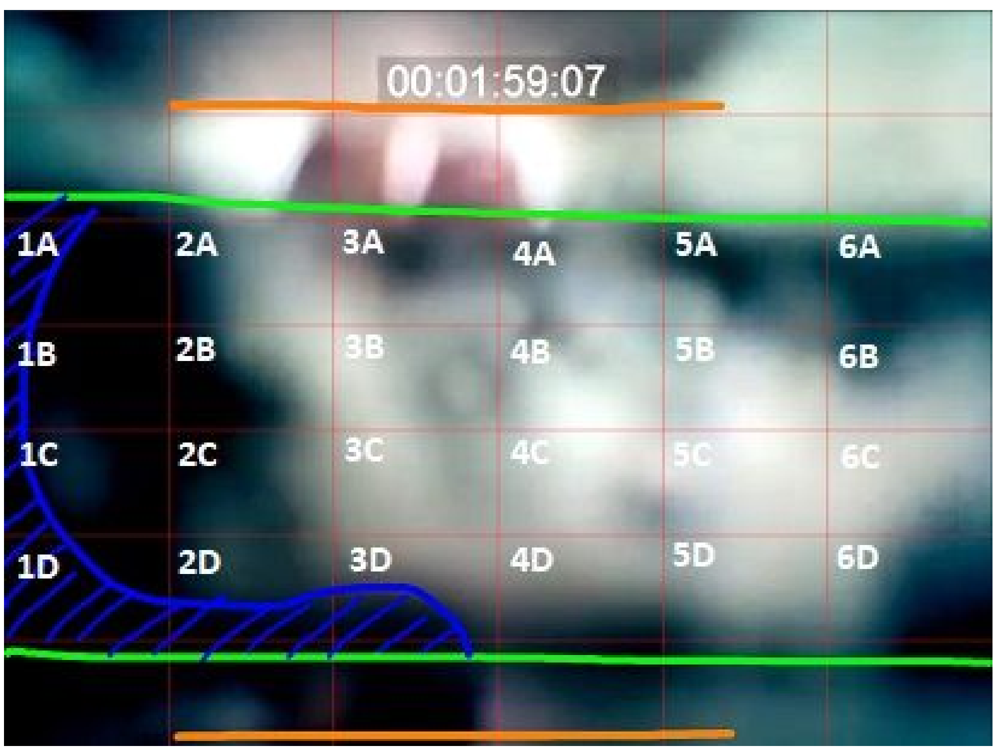


Figure 4: (t = 289 seconds) Chamber has stopped spinning and the charged debris beads are influenced by the electric field. Clumped primarily in Row D, the region nearest to

the negatively charged capacitor plate, and the top right corner, in cells 5A, 6A and 6B, near the positively charged capacitor plate.

Figure 5: (t = 311 seconds) Beginning of descent. The beads are forced first to the right, toward column 6, and then upward into row A.

6.3 Mission Results: 3D Printed ABS Material

Initially having been chosen due to its low cost and ease of version revision, ABS was not thought to be the ideal choice for component construction but was the most approachable for the project at the time. It was anticipated that the extreme heat of reentry would leave any component constructed of ABS unrecognizable and all electronics stored within any ABS enclosure would be destroyed. There was also concern that the G force experienced by the components could damage them on launch. It was for this reason that, except for the boom, only non-critical components were stored in ABS boxes. Our results however, proved that perhaps ABS could be used in more significance in future flights. Upon retrieval of the payload it was quickly determined that the ABS performed significantly better than expected.

The initial success was the plastics ability to withstand the G force of launch. As it was a known problem that could have potentially affected very critical components of the experiment, the team spent a large portion of time ensuring parts were printed in correct orientation as to align the layers perpendicular with

the force of launch and ensure %100 infill on all components. This proved to be a successful strategy as all, but one component survived reentry and all survived launch as can be confirmed from video data saved during flight. The single failed component broke during reentry due to a design flaw which allowed for too high a force to be applied to two bolts in the plastic. This failure could be rectified with thicker part walls (>5mm).
The most shocking results seen from ABS were its ability to withstand brief levels of extreme heat and its ability to insulate. Upon reentry the boom and supporting plastic boxes did not show signs of severe melting, instead the team recorded levels of burning on the outermost layers. Once the power regulation box was opened there was no sign of heat damage as both boards and wires were in pre launch condition. This insulating ability appeared to only require a few millimeters of ABS to work, as the lid for the systems power converters was only 10mm thick.

It is the team's belief that ABS should be heavily looked at in future projects as a potentially viable option for storage and protection of critical components. It is currently unclear if a secondary factor is involved with the survival of the payload's ABS components however a secondary flight to test the limits of survivability should be conducted. If proven to be a viable option for storage of sensitive and mission critical electronics ABS could significantly reduce the price point of future flights. Not only would it allow future teams to save the money typically spent on milling and manufacturing aluminum enclosures, it would also allow for a significant boost in version turnaround time. A typical part took only days for our team to design, print, test, diagnose, and reprint.

7.0 Conclusions

With all the minimum requirements for a successful mission outcome having been met and a lot of data, the team sees the mission as a success. The secondary experiment, the Small Debris Experiment, also worked as intended and we were able to gather data. The boom appears to have functioned successfully, deploying and retracting as expected, based on pictures collected from the onboard cameras.

8.0 Potential Follow-on Work

The results from Project O.S.C.A.R. prove the validity of the experiment and show that the mission should continue with the following modifications: higher level modeling, payload deck and electronics enclosure redesign, modifying the hand motor to include retraction, and incorporating testing into the viability of 3D printed ABS components to house critical components.

The next mission should begin with higher level modeling based on the information discovered during Project O.S.C.A.R. This modeling can then be utilized in the following improvements to the redesign of the payload, these redefined force calculations for the charge and the debris can be better executed.

The small debris collector experiment (SDC) could be improved upon with the use of more consistently sized resin beads for more accurate data analysis. The original method of underlit illumination with the use of an LED under the clear ABS resulted in shadows in the viewing angle of the camera making data analysis more difficult; a better angle of illumination is advised. The camera mount was also located inside the SDC thus making it difficult to access for focusing adjustments. It is recommended to make this easier to access for optimal viewing of the experiment. Altering the code in a future reiteration of the experiment, to allow for the capacitor plates to receive power after the beads were charged and the chamber had ceased spinning could allow for a clearer observation of the capacitor plates' charge influence upon the beads.

The payload layout should be redesigned for ease of troubleshooting and repair. Significant time was misspent taking apart and rebuilding the payload and electronics enclosure every time there was an issue. It is recommended to change the layout of the deck to incorporate a larger more rectangular electronics box attached to the plate which allows for opening from the top. This will ease the troubleshooting and assembly of the electronics system. With this layout redesign it is also recommended that the custom PCB design be revisited for ease of integration. With this new height restriction, it is recommended that the boom extension orientation be changed to side extension to maximize the available space.

The collector hand and motor should be redesigned to include retraction to help ensure there is no issue of back current when manual retraction of the collector. There is a strong indication that this may have been the issue on the most recent flight in the sudden failure of the hand collector motor.

This current flight showed the strong possibility of using 3D ABS printed parts to house more critical components with the survival of the step-down converters. These converters were housed in a 3D printed sleeve with a 3D printed lid attached with two screws, this design choice was made due to the fact these components were not needed to survive reentry. After recovery it was noted that inside the compartment the converters, wires, and labels were in almost the exact same condition as before launch. Future missions should continue testing and exploration into this result to assist with the cost restrictive nature of participating in space programs.

9.0 Benefits to the Scientific Community

This mission is based on the utilization of static electric fields to attract space debris, with mechanical and electrical charging systems. This mission applies to space debris research, performing reclamation via the method of external mechanical removal. The results include the extension of the boom and the change in movement of the simulated debris in microgravity and static electric field. Another option is to simply change the trajectory of the debris , lower its orbit and leave it to burn in the atmosphere. This mission will help to contribute to practical ideas such as this. Using the triboelectric boom arm to attract debris also helps avoid the complex designs of bionic robotic hands for capturing debris. The design of mechanically charging cost-effective materials and creating the static electric field with low potential capacitor could be applied for future study in the creation of the electrostatic field with lower cost in the space for other purposes besides debris reclamation. Other purposes could be studies in meteorology and astrophysics; for example, the development of detection of the weak and unstable electric field due to the change in upper atmosphere. Since this is related to the exposure of aluminum debris and positively charged beads to the electric field in microgravity in the space, it could also be helpful for fundamental research in space plasma. The behavior of metallic debris or delicate parts from space crafts in the static field could be potentially used to study the space plasma's influence in the low earth orbit. Also, the innovative small debris experiment with a spinning chamber could be improved and utilized for testing nanomaterials' or other polar macromolecules' formation under electric field and their reaction to it, which is beneficial to material science research.

10.0 Lessons Learned

The 2018 Community Colleges of Colorado Rocksat-X program was successful in almost every one of the particulars, with minimal descoping. This is made even more impressive by the project being a first year collaboration between three different schools, however, this is not to say that there were no setbacks.

When considering the initial design, the group had decided within the first couple of meetings the overall direction, and then divided up into teams to create the initial designs of the various parts - initially, the software, electronics, the boom, the collector hand, the Small Debris Experiment, and the electronics enclosure. While this part of design is vital in starting the creative process going, anything that comes out of this phase will bear little to no resemblance to the final product. Requirements will change, sometimes drastically, and will cause numerous reworks of the parts, before any CAD program is started. What is most important will be that every team should have a member who has some ability in sketching - technical drawing preferred, but any artistic ability recommended. This is one time where a picture is worth a thousand words, and a few minutes in front of a whiteboard is better than days of emails back and forth. This time is also when the team should start identifying the holes within the skillset of the team, and begin a very aggressive training regimen, of equal importance to the actual work on the payload. It is disheartening and demoralizing to everybody involved when work on the payload is bottlenecked due to only 1-2 members of the team having the skills to work on a certain component. This will slow down work at the beginning of the program, but by the end, it will pay back in dividends, both with this project and with future projects to come.

After the initial design, when a rough outline of the payload has been considered, digging down into the individual component design is perhaps the simplest, but still the area where you will have the most grief if done incorrectly. You must be aware of the environment your payload will have to withstand, from before launch to the moment it arrives back in your team's hands. Small, unsupported parts may break off, vibration may shake wires out of connection, and salt water will get into everything, no matter how much you prepare. Designing your components with these constraints in mind now will save many redesigns in the future. It is at this point that the importance of an iterative naming scheme will become apparent. It is important to get an inexpensive, disposable prototype into the hands of those doing the system integration as quickly as possible, so that they can give feedback on what changes need to be made before final printing or machining of expensive material is allowed. This is also where the teams must be careful in assigning reasonable parameters in both available weight and volume to each component of the payload. While it may be tempting to build exactly to the margins, a reasonable safety factor must be added to every parameter. And finally with regards to component design, remember that engineering is done with numbers. Analysis without numbers is only an opinion.

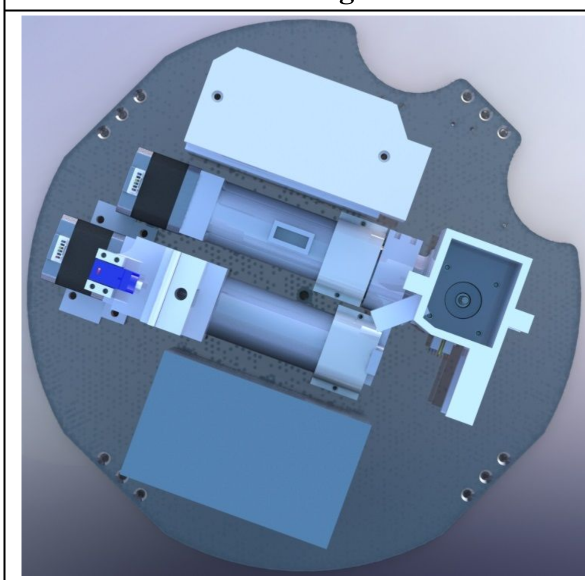
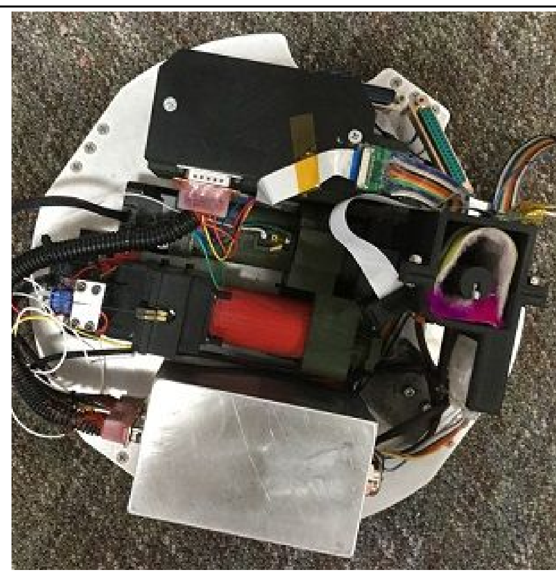
With regards to system integration, your team will spend more time on this aspect than any other aspect of the program. It does not matter how well the interfaces are designed, it will not come together correctly the first time. Parts will have to be redesigned in ways that the drawings would not have led you to anticipate. Being able to receive prototyped parts from the component design teams will make integration much easier, and allow the integration team to give valuable feedback on changes that will be required. And it is important to design the payload with an eye towards disassembling and reassembling it multiple times - if any part is glued, soldered, or pinned on so that something must be broken in order to disassemble the payload again, then it is a design that needs to be reworked.

Testing should be done first at a component level, then a subsystem level, then a full system level. No team has ever had enough time to run every test prior to launch that they had wanted, and so it is important to prioritize the tests by what is most mission critical to get right. Designing tests that will push the components to the margins can be challenging. Some tests will require specialized equipment, such as shake tables or large vacuum chambers. Knowing the numbers on your components will help you determine if they will work correctly outside of standard gravity if they perform as expected during the testing phase. And testing should continue up until the moment that the payload is handed off.

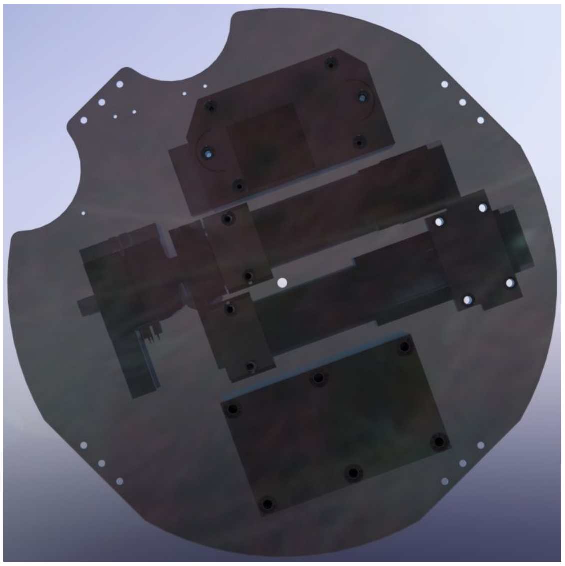
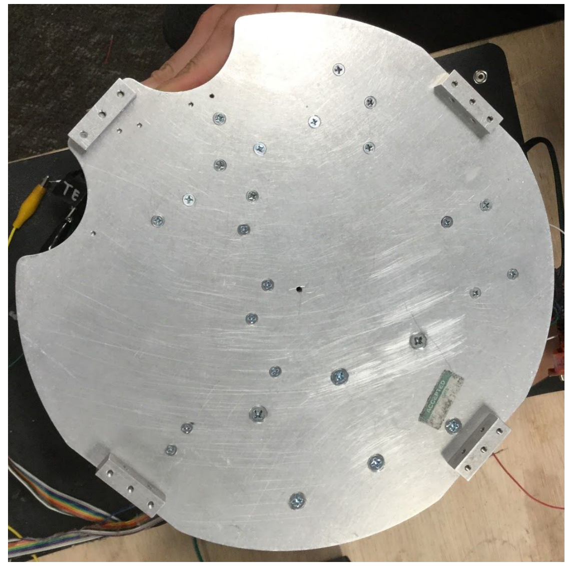
The final step, and one where most teams stumble, is in analyzing the data that they have received. The final step of the program is not when the payload flies, either successfully or unsuccessfully, but when the paper is presented, complete with analysis. Build the tools for data analysis alongside the physical hardware, and after the data is retrieved the hardest work of analysis would already be completed. The ideal would be to complete the analysis within days of the flight, while the momentum of the project is still fresh. But it is important that the entire team be as involved in this part of the project as they had been in the design and building phase.

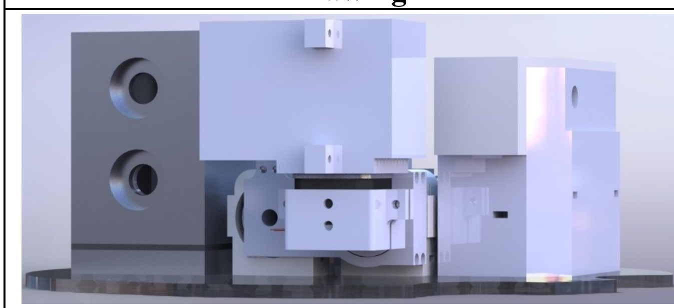
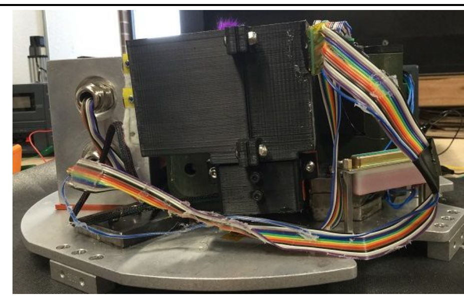
11.0 Appendices

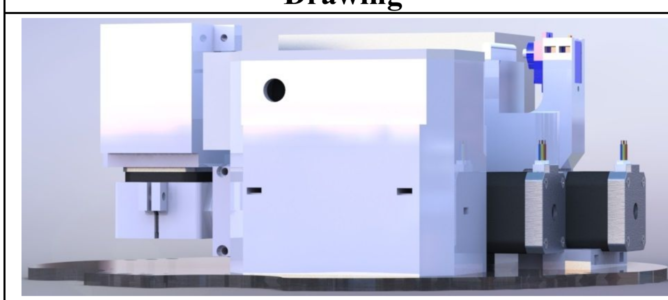
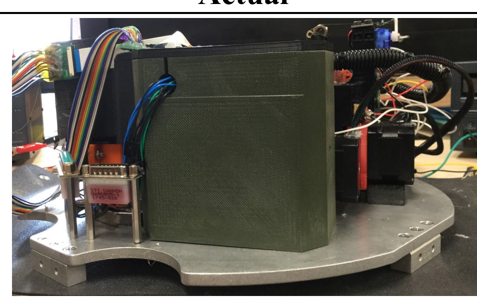
Thank you to the Wallops staff
David Colclazier
Liz Cox (IDEA Institute)
Jeremy Beard
Matthew Chase, and everybody at ORIGIN MEC
Mike Hoganson
Alexander Gibson

Payload Top View	
Drawing	**Actual**
	

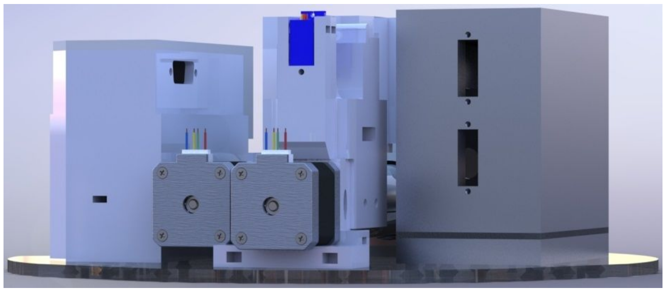
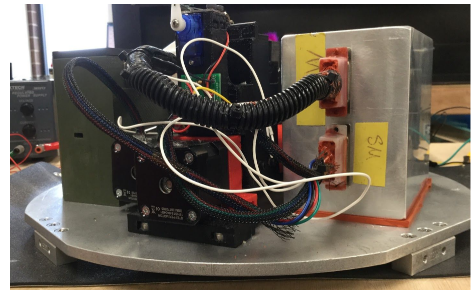
Payload Bottom View	
Drawing	**Actual**

Payload Side View (0 Degrees)	
Drawing	**Actual**
	

Payload Side View (90 Degrees)	
Drawing	**Actual**
	

Payload Side View (180 Degrees)

Drawing	Actual
	

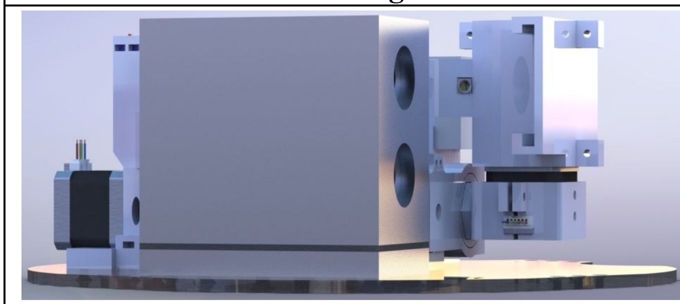
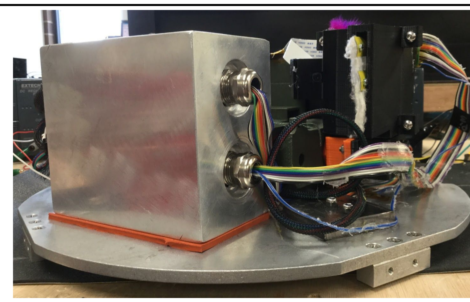
Payload Side View (270 Degrees)	
Drawing	**Actual**
	

Figure : Payload Renders vs. Actual from GSE Checkout

Requirement	*Status/Reason (if needed)*
Center of gravity in 1" plane of plate?	Yes
Weight 30.0+/- 1.0 (15.0 +/- 0.5) lbs?	Yes
Max Height < 10.75” (5.13”)	Yes
Bottom of deck has flush mount hardware?	Yes
Within Keep-Out Zone	Yes
Using < 10 A/D Lines	Yes
Using/Understand Parallel Line	Yes
Using/Understand Asynchronous Line	Yes, at 19200 Baud
Using X GSE Line(s)	Yes, GSE 1
Using X Non-Redundant PWR Lines (TE-1, TE-2, TE-3)	Yes
Using X Redundant Power Lines (TE-R)	No
Using < 1 Ah (< 0.5 Ah for half payload)	Yes, 0.39 Ah (Shared Payload)
Using <= 28 V	Yes
Using RF (If yes, list frequency and TX Power)	No
Using deployable?	Yes, but speed is under 1 inch per second
Whole team consists of US Persons	Yes
Using ITAR and/or Export Controlled hardware	No

Table : User Guide Compliance

The time sequence occurred as follows:
GSE On; t= -300s
Launch; t= 0s
Camera On; t= 170s
TE2 On (beads begin spinning); t= 252s
TE2 Off (beads stop spinning); t= 288s
Apparent Descent Begins (beads motion shift); t= 304s
Camera Off; t= 314s

References

La Vone, Michelle 2013, “The Kessler Syndrome Explained.” *Space Safety Magazine*, www.spacesafetymagazine.com/space-debris/kessler-syndrome/.