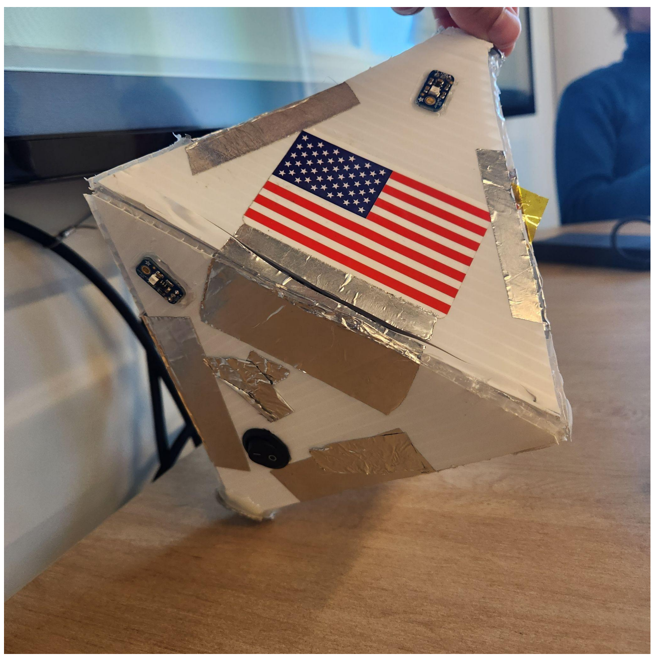
Colorado Space Grant Consortium

DemoSat
Design Document

Colorado School of Mines



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12.05.2022
Revision D

Revision Log

Revision	Description	Date
A	Preliminary Design Review	09.22.22
B	Critical Design Review	10.24.22
C	Flight Readiness Review	11.03.22
D	Analysis and Final Report	12.04.22

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1.0 Mission Overview

Our mission's goal is to create and send a payload into the atmosphere to collect data on UV light.

We were looking to conduct research on something *new* rather than repeating prior DemoSAT experiments and the topic of atmosphere, altitude, and light intensity was relatively untouched so we decided it was worthy of exploring in a new, innovative way. Of course, UV light is already researched— UV index is talked about often in weather reports and in health scenes when advising protection from the sun (for example, the recommendation of sunscreen use on especially sunny days) — however our payload would possibly offer a new way of going about collecting that sharable information.

According to the United States Environmental Protection Agency, currently UV light/UV index data is collected via satellite, computers, and ground observations. "The U.S. National Weather Service calculates the UV Index using a computer model that relates the ground-level strength of solar ultraviolet (UV) radiation to forecasted stratospheric ozone concentration, forecasted cloud amounts, and elevation of the ground." [1]

This method, while known to be sound, is heavily reliant on *several* factors… Our project, though new and experimental, can collect this data all within itself— no need to run simulations or compare different number sets to models and so on.

Preliminarily (Rev A), our payload design consists of an octahedral frame, fitted with glass lenses on each face, that focused light from all angles onto internal sensors. The thought with this was to be able to collect the most amount of data from any angle for each sensor. However, we ran into weight and safety issues and concerns about the integrity of our technology within the frame.

For our second decision (Rev B), we forged ahead with the octahedral frame but we decided to eliminate the lenses, allowing us to put sensors directly on the faces of the frame and collect data without needing to go through a "middle-man" (the lenses focusing the light). This not only increased the safety of our payload but also freed up our weight constraints and secured our confidence in the integrity of the sensors.

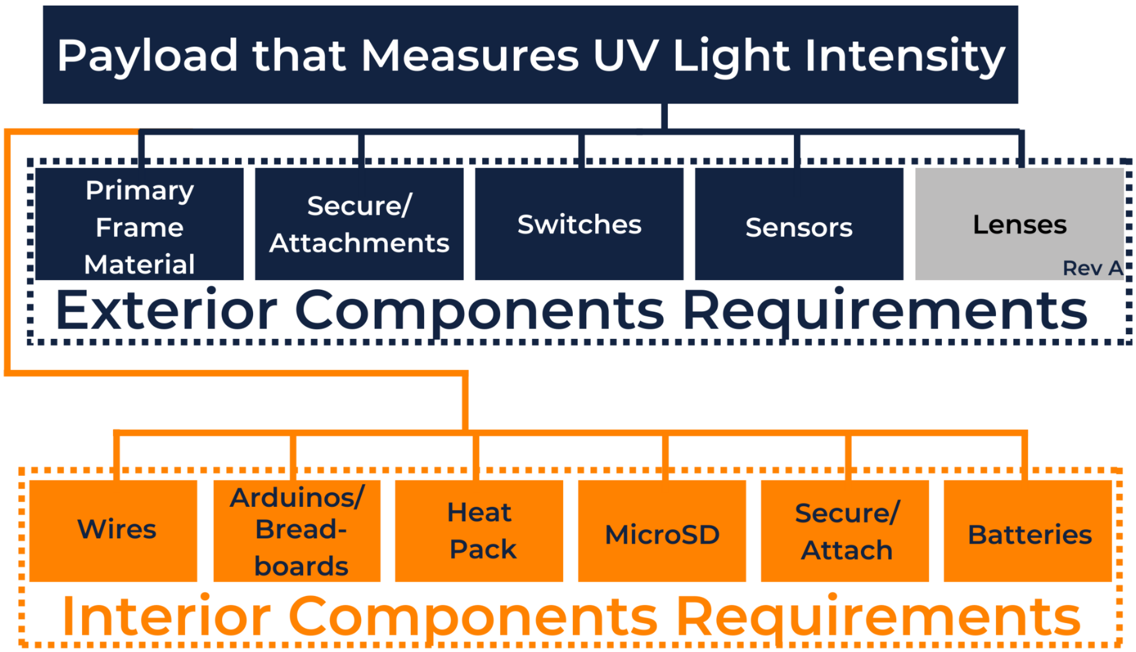
*These designs and our decisions/changes are discussed in more depth in section 3.0.

When data is collected, the intention is to compile the strongest points and graph each so that we get a curve including only the points when the sun is most hitting our sensors. This will most clearly reflect the UV trend and how much light is actually being transmitted through the atmosphere at that altitude.

We expect to see the general trend that, as the payload goes up higher into the atmosphere, the amount of UV light taken in will increase.

2.0 Requirements Flow Down

The requirement flow down chart we decided to use tackles the entirety of our project in two halves. Looking at required components for both the exterior of the payload and the interior of the payload can help simplify design and building tasks as well as greatly aid in the simplification/compartmentalization of larger tasks overall. Below (figure 1) are the two 'sections' that need to be tackled in order to fulfil our overarching goal/project.



Requirement Flowdown Chart

Exterior Component Requirements:

- Primary Frame Material—
  - It is essential that the material of the frame, and in turn the frame in its entirety, can withstand high impacts, low temperatures, and is lightweight but sturdy enough to hold interior and exterior technology during the launch experience.
- Secure/Attachments—
  - This subsystem is in charge of keeping the primary frame together, and just in general ensuring all components of the experiment and attached safely to the payload.
- Switches—
  - Since the primary frame is meant to completely seal in all electronics, there needs to be a way to activate things such as the heat packs, the sensors, and the MicroSD/Arduino overall from the outside before the launch. This is where exterior switches or buttons come into play.
- Sensors—
  - This subsystem is one of the single most important of the experiment, as everything hinges on these collecting data during the flight. They need to be functional and they cannot be easily damaged.

Interior Component Requirements:

- Wires—
  - Wires will connect every bit of technology within the payload. It is important they are fastened properly and won't break or come undone in order for the payload to collect the information it's supposed to.
- Arduino/Breadboards—
  - This subsystem is in charge of information transmittance and collection. Coded to run the sensors then gather the sensor's information onto a MicroSD, it is very important to have every line of code and every wire pin done properly.
- Heat Packs—
  - While the exterior is built for extreme conditions, it is important that any technology inside of the payload ends up frozen. The heat pack is important to keep equipment functional.
- MicroSD—
  - The MicroSD will be holding all data collected from the sensors and is important for our data analysis after the fact.
- Secure/Attachments—
  - As with the exterior, it is crucial that this subsystem is executed well. Every component within the payload's frame has to hold together without coming apart or getting damaged.
- Batteries—
  - This subsystem is important to the completion of the project as they power the entire system. Without functional batteries there will be no heat or data collection at all.

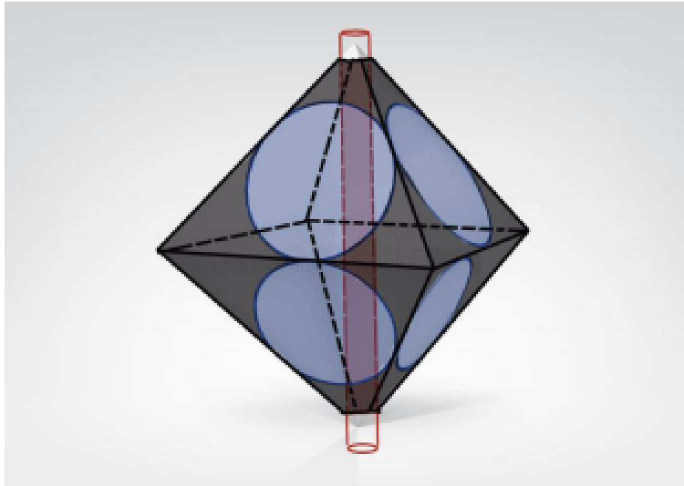
3.0 Design

Task (restated): Create a payload that will go into the atmosphere with sensors to collect information on atmospheric trends and UV light intensity.

Rev A: Design

Key Components—

- Eight-sided payload frame
- Focused lenses on each face (focused inward)
- Slot through center for flight tube
- Heating pads, batteries, sensors, arduino, wiring (inside)
  - Sensors directly in line with focused angle of lenses



Exterior sketch of preliminary concept (Rev A)

The goal of this design is to tackle collecting light at any angle to eliminate the errors caused by spin and shake while the payload is on the flight string and on its journey into the atmosphere. The eight sides of the payload will allow for eight angles and eight sensors which will all be collecting data at the same time.

Inserting focused lenses along each face of the payload will actively take light that hits it at one angle and force it towards the sensors, again limiting error caused by spin during the flight.

The primary frame will be foam core. This material has been used in previous DemoSAT experiments and is known to withstand the impact of landing and the temperature of the atmosphere. The lenses will be glass. They will be secured with hot glue and possibly 3D printed inserts. Sensors will be secured along inserted flight tube where the lenses are focused with hot glue. Everything else will be glued in as well, possibly to more foam inserts where the lenses are not.

Concerns about Rev A:

- The fragility of the glass during launch and upon falling down is a safety hazard
- Glass may be hard to secure onto the foam
- The focused lenses may be *too* intense for such a small frame and end up melting/damaging the sensors
- We may not meet weight constraints with thick glass frames

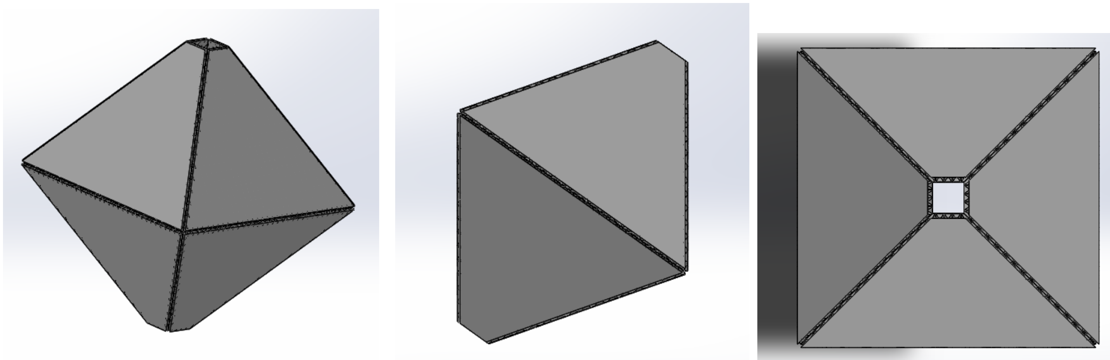
Rev B-D: Design

Key Components—

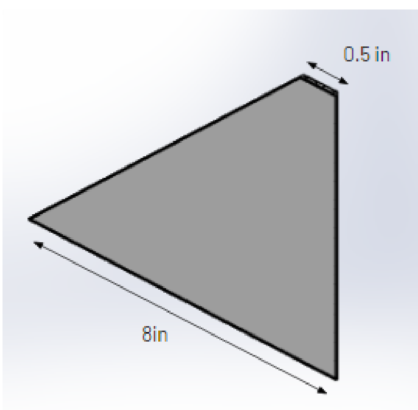
- Eight-sided payload
- Slot through center for flight tube
- Heating pads, batteries, sensors, arduino, wiring (inside)

Primary difference from Rev A: **Removal of Lenses**

(Below) Orthographic, front, and top views of new payload frame (CAD), showing the diamond shape and the updated material.



With the removal of lenses, almost every single concern about the payload and the experiment overall were eliminated. The team no longer has to worry about broken glass, exceeding weight limits, or damaging equipment with other equipment— and we are now free to focus on other things.



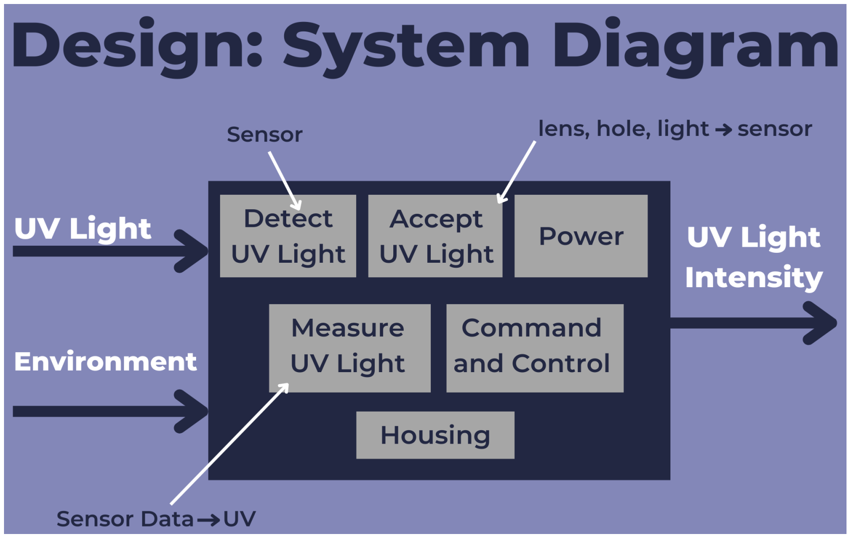
(Left) Each face will be a trapezoid-esk shape— a triangle with its top removed so that the flight tube can run through it with ease— and will be made from corrugated plastic rather than foamcore. The overall shape did not change and we are confident that it still optimizes data collection.

The material change, after some research, seems to be a safe bet as well— “able to withstand extreme abuse, the strong corrugated sheet has an impact resistance 20 times stronger than fiberglass and over 120 times stronger than glass. Resisting hail, wind-borne objects and vandalism, it can withstand over 235 pounds per inch of impact within a temperature range of -40°F to 240°F as measured by ASTM D 3029.” [2]

(Above) CAD Modeling of the Corrugation

With the question of framing no longer in the picture, the innards of the payload (wiring, sensors, power supply, etc) can be focused on.

Before getting into the interior design, though, we were asked to create a diagram considering our payload as the “system”; what will be going into the system, what occurs within the system, and what will come out of the system overall. The diagram below illustrates our thinking as far as what outside factors the payload will be encountering, what subsystems require what technology in order to process the external inputs, and then our overall goal of measured UV light intensity as the primary outcome.



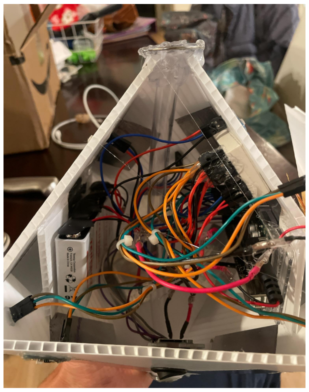
(Above) System Diagram for Rev B

As shown above, the components within the payload's frame include sensors, equipment that will store the data collected from sensors, and power, primarily. In this case, the technology used to capture and interpret the information accepted from the inputs were standard arduino wiring and components (including a small breadboard), an arduino mega board, and a microSD card with hand-written coding to sort information from each of the eight sensors into their own section.

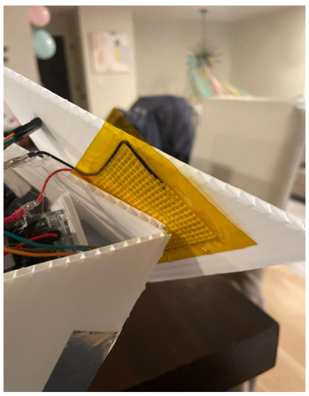
Extra interior features, covered in "power" and "housing", are the batteries, heating pads, and the switch that is installed along a face of the payload for easy access to turning the electronics on and off for launch.

Each electrical component is soldered together… Then hot glued to stay on *very* well.

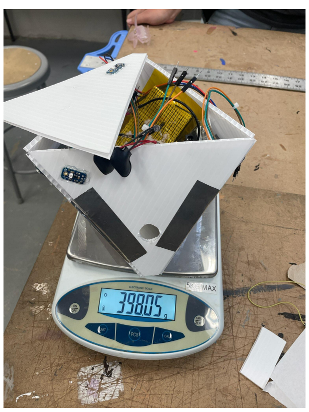
The frame of the payload, made of the corrugated board, secured with hot glue and aluminum tape. The washer for securing the flight tube for the flight string is also secured with hot glue. The switch, as with the sensors is fed through a cut in the plastic sheet and glued down to the face of the payload.



A view of the inside wiring, batteries, arduino board, and and breadboard surrounding the flight tube. Each sensor's wires can be seen leading to a face and poked through.



The battery-powered heating pack on the inside face of one of the triangular panels.



The final, unsealed payload with a completed weight estimate. Well beneath the weight restriction of 1kg this year.

Overall, the payload met size requirements with a properly fitted flight tube, weight requirements, and was able to withstand the environment it needed to. With an innovative design, the payload was able to collect eight sensor's worth of data successfully over the flight that resulted in trend lines similar to our predictions and can be analyzed and applied to many different real-life situations.

4.0 Management

The team was set-up where everyone would come together to agree on specific issues and decide as a whole, rather than a voting system or a single leader.

Teammate	Subsystem	Role	Date Finished	Notes
Bradley	Control (Arduino)	Coding	October 25th	The code for the arduino was the last component that was being debugged before launch
Kylie	Transport and Activation	Build and support	October 15th	The wiring and data acquisition from the arduino
Teli	Housing (Octahedron)	Builder	October 5th	The housing was the initial build piece that everything else fits in.
Marissa	Activation and Display	Creator	November 2nd	The activation switches turn on the arduino and the display slides for presenting data.

The biggest time limitations came down to a couple days before the launch when the arduino code was throwing a tantrum and pulling up errors. It was able to be solved by an acquaintance and resolved.

5.0 Budget

Weight Summary

Item	Dimensions (if applicable)	Quantity	Weight/Unit Weight	Total Weight/ quantity
Corrugated Plastic sheet	18”x24” (full sheet)	1	~44lbs/100 count ~0.44lbs/1 count	~0.44lbs ~199.58g *for entire sheet NOT triangle panel
Sensors	1.38” x 1.38” x 1.38”	8	.7g/1 count	5.6g
Arduino		1	25 g	45g

Breadboard	(No Frame) 1.75" x 1.38" (44.5mm x 35.1mm)	1	13.1g / 0.5oz	
Wires				
MicroSD Card		1		
Batteries			30g/1 count	60g
Heat packs				
COMPLETE				398.05 g

Cost Summary

Item	Manufacturer/Model	Dimensions (if applicable)	Quantity	Price/Unit Price	Total Price
Corrugated Plastic sheet	N/A	18'x24'	1	N/A	Free- provided by Mines Makerspace
Sensors			8	$5	$40
Arduino			1	N/A	Free - Re-using last years
Breadboard			1	$5	$5
Wires				$10	$10
MicroSD Card			1	N/A	
Batteries			2x2	$	$25
ALL COMPONENTS					$90

6.0 Test Plan and Results

In order to be prepared to launch, the structure of the payload itself needs to be tested as well as the data collection. To test the structures integrity, the team will perform a drop test down a flight of stairs as well as a shake test. It will also be subjected to cold tests to insure that the material used for the payload will not be destroyed when going through the temperatures of the atmosphere. After the structure itself has been approved, the light sensors and arduino collection will be validated, in order to do this, the team will leave the payload in the sun, and insure that data is able to be stored for collection.

The first part of testing that the team performed was the cold tests. A piece of corrugated plastic was put in a box with dry ice. The material held up nicely and did not crack or break. Knowing this, the tema moved onto the construction of the payload. After construction was finished, and sensors and ardiuno were tested. This test originally failed. The sensors were collecting data and sending it to the arduino, however the SD card would not save the data for later use. After working on the code and correcting it, the sensors and arduino were able to effectively collect data. This test needed to be done again. After fixing the code, the payload was left in the sun, and when looking at the data, the were numbers for the UV. The sensors and arduino were then installed into the payload. To ensure data would be able to be collected in the cold temperatures, a heating pad was installed onto one of the panels that was tested in a freezer. The payload was left in the freezer, through which data was able to be collected and all parts of the payload stayed warm. After this, the payload was closed for the drop and shake tests. Once the payload was fully sealed, it was dropped down two flights of stairs. After both drops, the payload stayed intacted. The payload was then violently shaken. When opened, the contents on the inside were all still connected and working.

7.0 Expected Results

By launching a probe into the upper atmosphere with many ultraviolet light sensors on it, we hoped to get a good idea of how the thickness of the atmosphere affected the amount of UV picked up. This is known as the UV index, and typical levels range from 0 to 10, with 10 being the highest. A factor that we expect to affect our data is that the probe will be launching at sunrise, and as the sun gets higher in the sky, that will also affect the UV index. To combat this, the probe will be ran during another day on the ground to see how the position of the sun in the sky changes the UV picked up. Despite this, the data should still follow a very clear upward trend. This is because air pressure falls off in a (roughly) exponential way with altitude, and while the pressure at sea level is close to 15 psi, the pressure at 100,000 feet is closer to 0.1psi. This means that there is a lot less atmosphere between the sensors and the sun, and we expect the UV index to go well above 10. As far as data collection goes, all eight sensors take a data point every second. This is stored, in comma separated value format, on an SD card to be analyzed later. The data comes out of the sensors as a current value, measured in micro-amps. This correlates directly to UV index.

8.0 Launch and Recovery

The BalloonSat was launched by Teli Pinkerton and the whole team walked out for the retrieval. When arriving on site of the landing, the Octahedron was undamaged and the data was retrieved by taking the SD card from the arduino and exporting the resulting text file of data to a laptop to be viewed. This plan for data retrieval required that the payload go mostly intact through the flight, as long as the internal SD card survived. This plan was decided on because of the difficulty of transmitting data live. By including an onboard memory it simplified the project greatly and the retrieval was tested when the drop test was done to make sure the SD didn't become compromised.

9.0 Results, Analysis, and Conclusions

Fortunately, the payload was able to successfully collect data from all the sensors. However, the data collected was very rough. This is likely due to spin on the payload, from wind or other sources. *Figure 1*. shows the raw data from all eight sensors, on one graph.

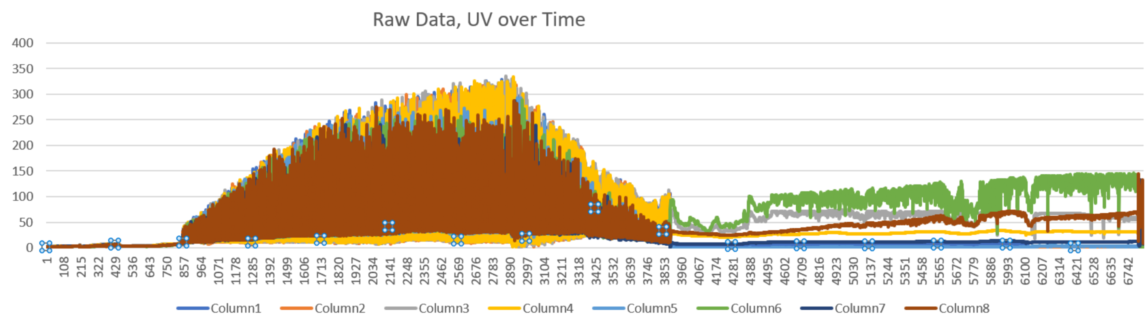


Fig. 1

Here, the different colors represent different sensors, with 1-4 being top sensors and 5-8 on the bottom. In looking at data from the top and bottom groupings of sensors, we found little difference in the trend. Despite the roughness of this data, there is a lot to be learned from it. First of all, we can extrapolate that the flight lasted from roughly 800 seconds to 3800 seconds, which means it was in the air for just under an hour. This comes from the fact that some sensor values abruptly go to zero as they face the ground upon landing. Additionally, as predicted, the top and bottom sensor groups show the same trend, but the bottom is slightly lower, as the incident angle with the sun was less.
In order to smooth the data and get something more useful, the maximum value from all eight sensors was charted for each data point. The maximum value is the useful value here, because it represnts the sensor pointed most directly at the sun. However, this still produces very rough data. This is because every second, there was not always a sensor pointed at the sun. To compensate for this, the max value from every 9 data points was taken. *Figure 2*. shows the maximum values (blue) overlaid with the max value from every 9 data points (orange). The chart has also been cropped to the duration of the flight.

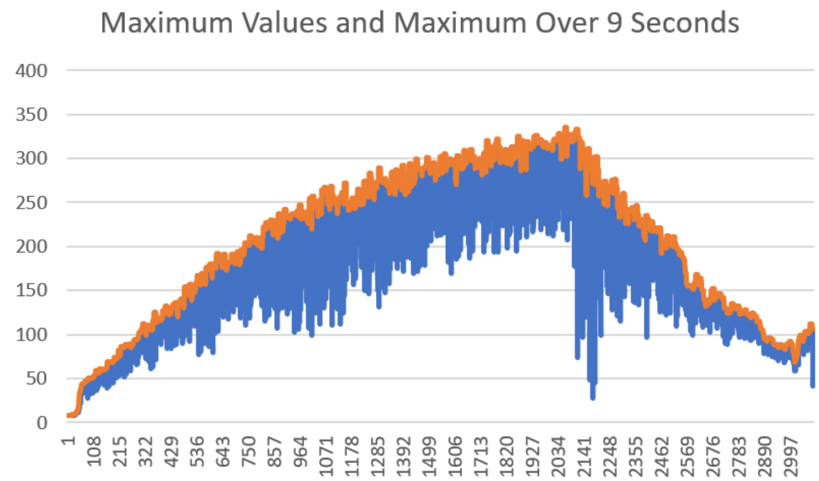


Fig. 2

Importantly, the problem of removing the influence of the time of day is also solved. Once the payload had settled into one place after landing at 4300 seconds, sensors 6 and 8 were pointed toward the sun. We can see a linear increase in the UV they picked up, despite them being stationary on the ground. From here, a linear trendline can be used to find the rate of increase, and then subtracted from the data in *Fig 2.* The trendline and associated data are shown in *Figure 3*. The irregular dips and peaks are times when some grass was blown over the payload and caused a brief change in the sensor reading. This did not affect the trendline in a significant way.

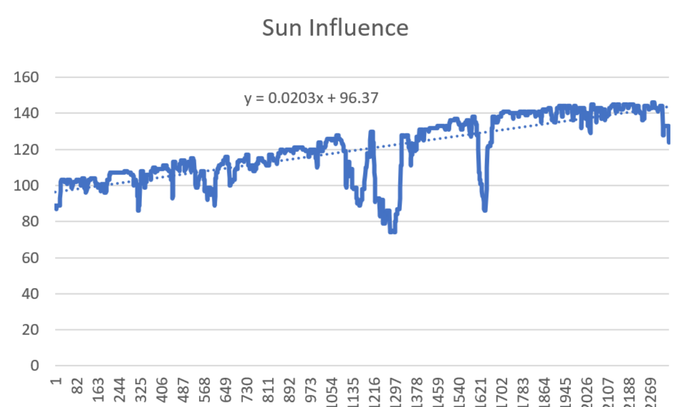


Fig. 3

To remove the influence from the flight data, the equation provided by the trendline was used, with x being the time. The resulting value was subtracted from the UV data. As shown in *Figure 4.* and *5,* doing this flattened the curve where the payload was on the ground, and slightly lowered all the other data. This is how we know it worked. Places where the data went negative are places such as the previously described ones with grass interfering, where the data did not line up with the trendline.

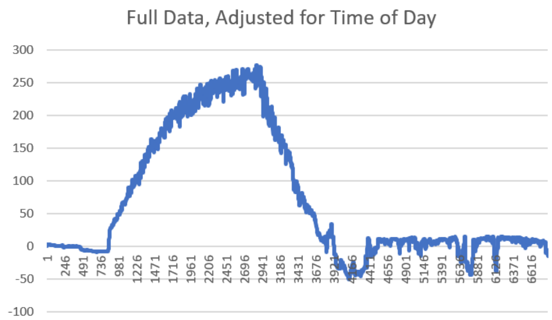


Fig. 4

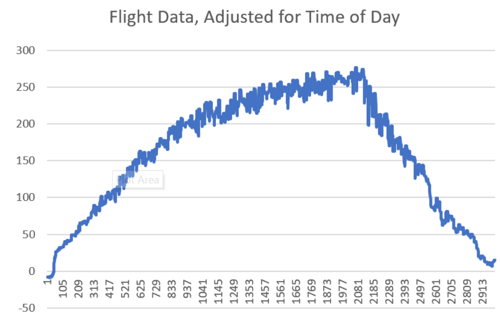


Fig. 5

Figure 5 is the final UV data. However, this is still a fairly arbitrary "photocurrent" and needs to be converted to UV data. In order to do this, the formula $\frac{SensorValue \times 5.0V}{1024 * 0.1}$ is used. This comes from the sensor data sheet, and outputs a UV index. *Figure 6* shows the final UV index chart.

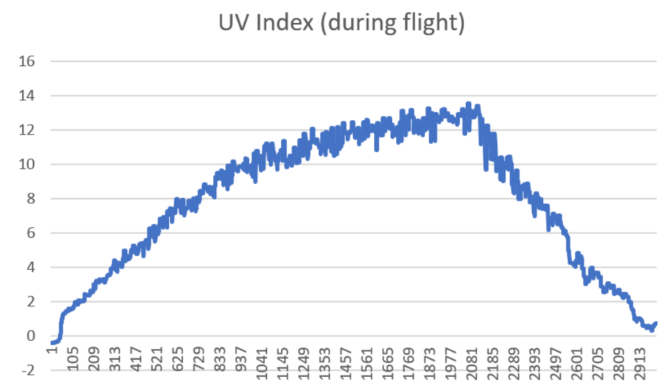


Fig. 6

In Limon, the average maximum UV index for November is 2. However, just as we predicted, this is not the case at 110,000 feet. Our payload saw a maximum UV index just shy of 14, far higher than seen on the ground. This clearly shows that the thickness of the atmosphere has a strong impact on the UV index.

10.0 Ready for Flight

The payload after the flight was in almost pristine condition, with the only issue being that some of the internals were beginning to become loose. To secure these firmly in the future we can apply an adhesive material to more components to make sure they don't undergo the same stresses throughout the flight. The storage of the payload isn't complicated. The switch needs to be turned off and the payload needs to stay in a dry and non abrasive place, most likely in a box. In six months the batteries would need to be verified but other than that the payload should be able to fly again. Since the arduino has a non-volatile memory storage of the sensor code it doesn't need any additional capabilities to fly in half a year from the first launch. The payload is turned on by two switches, located on an external face, and just would need to get the batteries replaced and then switched on for activation.

11.0 Conclusions and Lessons Learned

The Demosat Project gave the team an opportunity to expand into a new realm of engineering design research. The process of building a device to serve a specific purpose for the sake of gathering data rather than completing a project because of the school assignment and grade aspect was an overall positive experience. A project such as this makes it easier to learn how to perform tasks because of the desire to know the outcome. With most projects the only outcome has been getting assigned the percentage of correctness that was achieved, but with Demosat the result was more ambiguous and the direction was decided upon by those involved in it, which lends itself to providing more of an incentive to participate.

The team has learned many new things, such as arduino coding, breadboard wiring and diagrams, physical creation and testing of unique shapes, and the launch itself. What each member learned was mostly dependent on what subsystems were completed, but the team as a whole gained a nonzero degree of knowledge in most areas.

If done again, the project would include much more intricate data structures and the addition of a larger variety of data collection. The chance to include more functionality to the existing project would be the most straightforward and beneficial addition to the current payload.

12.0 Message to Next Year

The biggest hurdle we ran into for this project was choosing a topic. For future teams participating in the program, we got our initial inspiration from looking through past years reports, and combined it with ideas we all had and were interested in. Then, our other hurdle was getting the programming to work. This was a problem because we had thought it was all working well before launch, but about a week before we found out it had a bug. This was a problem caused by lack of testing, and had we done more comprehensive tests we would have found it. However, everything worked out in the end, and we were able to get good data.