July | 20

Elijah Balloon Payload Interim Report

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The 2010 Elijah Balloon Payload Project is well underway. The first few days of the project were spent at Dr. Farrow's cabin up north in Minocqua, WI. Between team bonding, canoeing, watching shooting stars and a beaver, the six members of the team made progress at the local library researching payload options and phenomena that pertained to both high altitude ballooning and team interests. A list of potential project ideas was created on this retreat, and consisted of main topics such as static charge, magnetic field, atmospheric composition, infrared photography, noise/decibel levels, long-range electronics/Wi-Fi, and solar power.

This list was then broken down into more specific categories where experiment ideas could be formed. Research continued for several days to determine the feasibility of the ideas and the methods of obtaining reliable measurements. The team then compiled a new list of the most intriguing and captivating ideas:

- Solar energy and efficiency
- Static/ electric charge
- Atmospheric composition
- Visual data (camera, video)

Three sub-teams were then formed to focus more in depth on these main ideas and continue to determine their feasibility and method of experimentation. It was agreed upon that the cameras and video will be materials that everyone would like to share and be part of, so that has been set aside for the moment. Any leftover weight in the payload will be designated for this purpose.

Sub-Team One: Solar Energy and Efficiency

With oil prices increasing and the harmful bi-products created from fossil fuels, alternative energy sources are necessary in order to answer the increasing demand for power. The sun hits the Earth with roughly $4.3 \text{ X } 10^{20}$ Joules of energy every hour. This is enough energy to fulfill humanities energy needs for an entire year. Why do we not try to satisfy most or even all of our energy needs with this unlimited and underused supply? The answer is the lack of efficiency.

Today's solar cells only have an efficiency of around 15-20%. This means that if a cell gets hit with ten Joules of energy, only about two Joules can actually be obtained through the cell. This low conversion factor, combined with the cost of producing solar cells makes solar energy just as costly as or more costly than fossil fuel energy sources. Another problem is that when the sun goes behind clouds or moves across the sky, the amount of light hitting the panel is not consistent.

A solar cell, also called a photovoltaic module, is made of multiple layers that are used to reflect light in a way that creates an electric current. Figure 1 shown to the right depicts the different layers mentioned. Solar cells are typically made of the element silicon. Silicon has fourteen electrons, four of those being valence electrons. Because of these four valence electrons, pure silicon in its crystalline form leaves no free electrons to move about, making it a poor electric conductor. In order to make silicon more conductable in a solar cell, impurities are inserted. In the N-layer, phosphorous is mixed with the silcon to create an imperfection in the silcon crystal structure. Phosphorous has five extra electrons, which means that when it bonds with the silicon there is one free electron to move around. It is called the N-layer, N standing for negative. When light hits one of these electrons, it breaks free of its proton bond creating a hole in the crystal. This electron then moves about the structure to find another hole that it can fill.

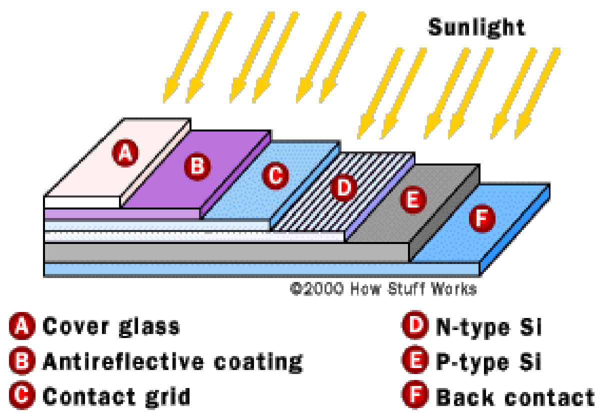


Figure 1: The layers of a solar cell. Different layers are used to make the cell a better conductor.

The other layer has boron mixed with the silicon. Boron has only three extra electrons. This creates a positive layer, known as the P-layer. When these two layers are put into contact with one another, all the free electrons move to the boundary between the two layers and an equlibrium is reached. Equlibrium means that all the electrons are in their rightful place and there is no net charge. If energy in the form of a photon hits the layer near the contact area, it will send an electron from the P-side to the N-side, creating a hole in the P-side. This electron will want to get back into the newly-created hole. If a path is created from the N-side to the P-side, this free electron will follow that path creating an electric current. This current is what is used to generate solar power.

In our experiment, we hope to test how the power output of a solar cell varies as it goes up in altitude. It is known that the amount of sunlight is significantly greater higher up in the atmosphere than that on the Earth's surface, so solar cells should be more efficient there. This is due to the lack of cloud cover, smog and the atmosphere attuenuating the light rays. With these concepts reducing the light and possibly the output of a solar cell, would it be reasonable to suggest a solar base above the clouds some day.

The amount of light that gets absorbed or defracted within the atmoshpere is called extinction. Figure 2 below is a plot that shows the results of a study condcted by the University of Southhampton's School of Engineering Sciences on the amount of extinction that occurs throughout the atmoshpere. As seen in the graph, a significant amount of light is extinct as is gets

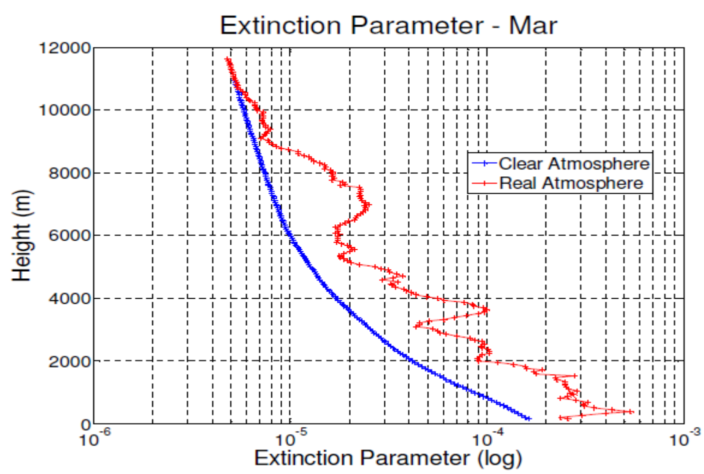


Figure 2: Amount of extinction throughout the atmosphere**.** Higher altitudes are exposed to more light because less of it is absorbed.

closer to the surface of the earth. According to this data, the amount of power output by a solar cell could increase by as much as 600% by positioning it at an altitude of 12000 ft. Figure 3 below shows the different values of power outputs from a similar study by University of

Southhampton's School of Engineering Sciences. Based on the information from this English study, we predict that we will see a steady increase in power output by the cell as the payload goes up in altitude.

Altitude	Yearly output from 1kWp facility [kWh]
Ground Based	1130* (750-900)**
6 km	4170
12 km	5480
Geostationary (Solar Power Satellite)	12000

*Value directly calculated from the Irradiation at Southampton

** Practical values suggested by manufacturers of PV for installations in England

Figure 3: Expected output from a 1 kW solar cell. Higher altitudes allow for more power output.

The way that we plan to test this hypothesis is to construct a solar tracking system that will keep the solar panel centered on the sun for a majority of the flight. A system that keeps a cell pointed towards the sun increases output by about 30% according to J. Rizk and Y. Chaiko. This statistic will also be tested through ground testing. The main reason for doing this is to keep the cell from getting off-centered, thus lowering the output of the panel throughout the flight. By keeping the cell centered on the sun, the error between ground tests and altitude testing should be greatly decreased. The tracking system will consist of a cross shaped holder that has five photo resistors attached to it, one in the middle and one on each appendage. Each resistor is then connected to a basic stamp input through a voltage divider. When the sun hits one of the side photo resistors it lowers the resistance in the voltage divider, causing the input signal to the basic stamp to go higher. The basic stamp senses this and turns a servo motor so the cell rotates until it is perpendicular to the sunlight. A diagram of this is shown below in Figure 4.

We will measure the power of the solar cell by connecting a resistor in series to the cell. As the current produced by the cell travels through the resistor, it creates a voltage. By measuring this voltage and using the known resistance, power can be determined through Ohm's law. The way that the voltage will be measured is by sending the voltage into an analog/digital converter, which will then convert the analog voltage into a digital reading. This digital reading will then be sent into the basic stamp and stored there.

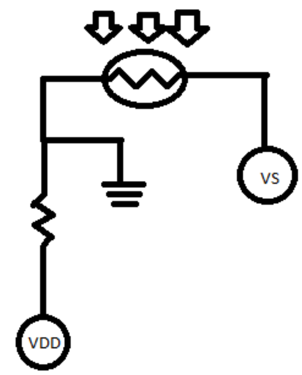


Figure 4: Voltage divider used in solar tracker. If a photo resistor other than the center one has sun on it, the servo motor will turn the cell in that direction.

High in the atmosphere are winds that could potentially break off or disrupt our tracking system. Since the device can only weigh about one and a half pounds, we had to come up with a way to battle the wind. Rather than weighing our system down by increasing its integrity, we worked around the problem by encasing the system within a dome. This dome will also be used to protect the system from the high altitude temperatures as well as moisture within the atmosphere.

For the remainder of the summer, we will finish the tracking system to make it as fast and efficient as possible. We will also be doing various ground tests in order to test different aspects within our hypothesis, such as whether or not the tracking system increases power output.

Sub-Team Two: Static Charge and Electric Discharge

The second sub-team is researching and experimenting with static charge and electric discharge. After intricate research, we found it interesting to look into how static charge is built up on objects that reach higher altitudes. The concern is that there are a number of aircrafts and other objects involved with high altitude flights that need to be aware of static build up to ensure the safety of the product, its hardware, and possible passengers that are involved. Static charge occurs at all levels within the earth's atmosphere and it is imperative that research is conducted in to understand how various atmospheric levels affect objects. Charge has the capability to be fatal, so it is imperative that scientists know how to enter those altitudes in a safe manner. This research will be influential and help corroborate other research that has been done.

The design of the experiment for static charge involves circuitry and programming to detect if a static charge is present at various altitudes as the payload balloon rises to about

100,000 feet. We will be testing the buildup of static charge on the payload balloon itself until it bursts upon arrival of the 100,000 foot mark. The setup of the design includes a circuit board that the components will be bonded to, one junction gate field-effect transistor (JFET), one 9V battery, a wire that will help identify the static charge, and a basic stamp.

The circuit board will involve soldering components such as a wire connected to the gate of the transistor, a JFET transistor, and several wire components. The length of the wire has been tested to show that as length increases, the distance the static charge could be detected did not increase. A JFET transistor is a device that contains a long channel of semiconductor material, made to contain a number of positive charge carriers, or negative charge carriers. An LED was used for testing purposes to make sure the circuit is working, but it will not be needed for the final project. When the LED turns off when static charge is approaching, the channel has negative charge carriers and is considered to be an NPN transistor. On the other hand, if the LED turns on when static charge approaches, the transistor has positive charge carriers and is called a PNP transistor. Contacts at each end form the source and drain. The source end of the transistor connects to the power supply; the drain is connected to an LED or other component to indicate that the charge current has passed through it. The gate terminal is where the wire is connected to, which is where the static charge is detected from. So when a balloon is statically charged by rubbing it, bring it close to the wire will turn it off. When it is pulled away, the light turns back on. This means that the transistor we will be using is an NPN transistor. "The flow of electric charge through a JFET is controlled by constricting the current-carrying channel. The current depends also on the electric field between source and drain; similar to the difference in pressure on either end of the hose" (Temic). The 9V battery strictly provides power to the circuit and the basic stamp is what allows the circuit to be programmed and allow us to receive feedback between the circuit and the computer. It involves a certain type of software specifically for the basic stamp and has its own programming language.

Over the course of the first three weeks, we have performed various ground tests to make sure a static charge will be able to be detected with the circuit we are moving forward with. We concluded that the circuit can identify a static charge from a balloon onto the payload. Figure 5 below shows several experiments involving a mock payload similar to the real payload. This mock payload was then hung from a tree for a couple of hours to see if it would gain a charge.

The payload did gain a charge that could be detected from about one meter away. The next experiment we put the circuit inside the payload including the detecting wire and brought a statically charged balloon near the payload to see if the charge could be detected. The results: it *was* able to be detected coming from any direction of the payload. For the third experiment, we put aluminum foil on the outside of the payload to see if this would affect the ability to detect charge when the detecting wire was inside. We found that the charge could not be detected in this manner. The aluminum would not allow for the charge to penetrate the payload. When the detecting wire was stuck through the aluminum so that it was not inside the payload anymore, the charge *was* detected, but it could only be detected on the side that the wire was sticking out from. This is interesting, because it contradicts the first experiment where the static charge was detected from all directions. When aluminum was applied and the wire was sticking out, the charge was only directionally detected from that side of the payload.

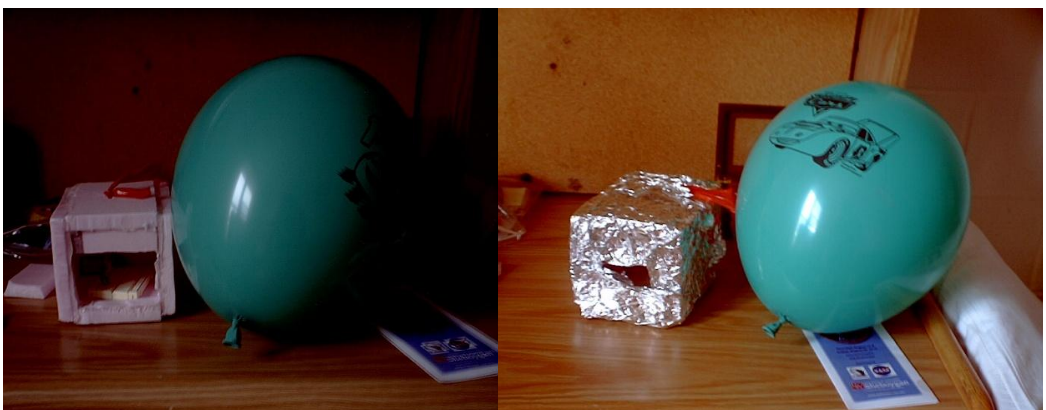


Figure 5: Mock-payloads including balloon and circuit inside. The picture on the left is the original payload with no changes to it. The picture on the right includes aluminum foil on the outer surface.

Smaller experiments were also run, including testing the length of the wire, the size of the balloon, and the effect of coiling the wire. We concluded that the longer the wire was, the shorter the distance of detection. When the wire was coiled up, the distance of detection was shorter. When the size of the balloon increased, the distance of detection greatly increased. The distance of detection is very important in designing this experiment because the distance from the payload to the weather balloon is around ten feet, and that is how far the static charge needs to be detected from. Since the size of the weather balloon is very large compared to the payload, this will increase the feasibility of the experiment. Several future experiments include testing the circuit in a bell jar to see how it is affected by temperature and pressure, which is a prominent concern during flight. Also, we must ensure that the basic stamp reads everything correctly.

The main concerns for this experiment are to decide how the circuit will detect the static charge by experimenting with the basic stamp program. The circuit we will be moving forward with will be able to detect if a static charge is there or not but there is not a definite way to detect a quantifiable amount. The second main concern is that the circuit must be able to withstand the temperatures and pressures up to 100,000 ft. This means that it will need to have good insulation, which the other experiments will need as well.

Researching past work with static charge was difficult, but we did find several experiments that have done on balloon gondola's that were very helpful in seeing how static charge changes as the altitude increases on an object. A graph in the article "Balloon Gondola Charge and its Estimation" written by S.C. Garg and T. John shows that in the two flights of the balloon gondola, the potential voltage or static charge reading decreased as the altitude increased. If we were able to get a voltage reading, this is what I would expect to see as well. These two gondolas went to the height of around 100,000 ft which is the range that our weather balloon will be reaching as well.

Other articles, explain the conductivity and why static charge is so important to research. "The charge accumulation increases in clouds and precipitation as well as when the humidity is above twenty percent. When it is below twenty percent the conductivity is poor. Objects such as our payload will have static charge greatest at any points or corners; if they are rounded, then the charge will be more evenly dispersed. It is important for objects to have a small amount to no static charge build up on them because they can cause lightning in clouds or in charged atmospheric conditions" (Gardiner). Clearly the possibility of fatality is motivation for this research.

A final article that we have researched comes from the Houston Astronautics Division that states that their "shuttle orbiter operating in the topside ionosphere will acquire a low negative potential on its outer surface" (Neubaur). The experiments that we have been testing have also gained a negative charge, so we agree with this article. We will not be operating in the ionosphere for the flight of the payload, but it is an example of what occurs in the upper atmosphere.

The second phenomenon that we decided to look into was electrical discharge or breakdown voltages. The breakdown voltage is the potential difference across a small gap that causes a gas, or other form of matter, to change from being an insulator into a conductor of electricity. This happens in a gas when the molecules start to break apart and become ionized until a small spark can be created through an area filled with that gas. The reason that we wanted to look into this phenomenon is that the breakdown voltage decreases as altitude increases. To cause electrical discharge, one has to have the right conditions. It depends on temperature pressure, humidity, and even the geometry of the electrodes that are used. Unfortunately for us, all of these except for the geometry will be changing throughout the course of the payloads flight.

Not only did we see this phenomenon as an interesting thing to explore, but it is also very important. Every electronic device, whether or not it is on an airplane, a missile, or in a balloon payload, is susceptible to arcing, which can ruin integral parts of electronic systems if the device is not insulated properly. These arcs can cause shorts in circuits that can completely disable and ruin machinery. This is most often seen in antennas for airplanes and missiles. Since antennas have to be either outside or near the outside of the device in order to communicate, they are more exposed to the temperature and pressure changes at different altitudes. Therefore, they have lower breakdown voltages, which increase the chance of arcing. Although there are ways to alleviate these issues, such as widening air gaps and pressurizing electronics whenever possible, it is still hard to figure out when something is going to arc because it is not oftentimes researched. In fact, many people do not look for the breakdown voltage because it is seen as a flaw in circuitry that should be avoided at all costs.

After we determined that this phenomenon was of importance, we determined an experiment that could be carried out to measure or to show the voltages. Our idea was to have one gap with movable contacts. That way the gap could start off larger and keep moving closer to the other contact until it sparked and then it would reset itself. We figured that this would be the best way to set up the experiment so that we could catch the change in breakdown voltage based on different altitudes.

Throughout the design of the experiment, we ran into a few questions that had to be answered. What voltage should we use and how we will create this potential difference? The breakdown voltage of air at standard room temperature and pressure is 3 kilovolts per centimeter. This seemed to be nearly impossible to reproduce. There was no way that we would be able to create and maintain this potential difference. Luckily we saw that due to the differences in temperature and pressure, the breakdown voltage needed was significantly decreased. This was very convenient because we could take advantage of this and use a smaller, more controllable voltage. Using various equations, we calculated what the temperature and pressure would be at different altitudes that the payload would reach. Then we plugged in these numbers into the Paschen's Law equations in order to figure out the estimated breakdown voltage of air. By using this process, we found out that we could easily get sparks to fly by only using 500 volts instead of 3 kilovolts. This made the design of out circuit a bit simpler and safer.

The next thing that we had to look at was how to step up the voltage from a power supply provided by a battery. We thought to simply use a transformer to step up the voltage, but with a little bit of research we found a DC to DC converter would work much better. This way, we can take 5 volts and change it into 500 volts. Although it was an expensive component, the part took away a lot of research due to the fact that it would have taken a lot of time to gain enough circuitry knowledge in order to step up the voltage. The DC to DC converter from PICO Electronics helped to relieve some worries about having an overly complex circuit and allowed us to minimize the size and weight of the circuit board.

The next issue to tackle was how to build the design of the moving contacts. For this we decided that a servo motor attached to a gear rack would be sufficient to move the contacts back and forth. This lightweight and inexpensive design has the servo motor positioned upside down so that it connects to the gear rack in a track. We also used the calculations from the estimated breakdown voltage to determine that the gear rack only had to move 0.8 cm so that the design could be condensed. The last thing that we had to look at in the design of the experiment was the fact that we needed both the circuit and the arcing gap both separate from each other and the rest of the experiments. Due to the fact that we do not want the arc to jump to any other electronics and we also do not want the 500 volt circuit just left out in the open, we created two distinct chambers in the design. Using Solid Works to finalize the design, it has been sent to the Rapid

Prototyping Center at MSOE to be fabricated.

Although these problems have been solved for the time being, there are still a few things that will need to be addressed in the near future. The first thing is learning exactly how to use the DC to DC converter within our circuit to create sparks, but not short the circuit. This is a delicate process because the DC to DC convertor is extremely sensitive and expensive. If we break it, not only do we have to pay for another one, but there is no way that we could get another one in time because the part is backordered and takes two weeks just to be modified for our needs. The next thing is that we need to be able to read when a spark jumps by showing that there is some current on the other side of the gap. We cannot simply run the wire to a basic stamp due to the high voltage. The last foreseen issue is how we will relate the readings when the spark has jumped to the movement of the servo motor. This will probably just need to have some careful programming of a basic stamp, but it must be looked into further.

From the beginning of the summer to the halfway point in the project, we have learned a lot about circuitry and programming. This opportunity has really expanded our skills and they will be very useful in the future for job opportunities and future classes. So far we have made great progress towards possible experiments. Although all of the specifics have not been worked out, continuous progress is being made each day so that the experiments will be ready for launch.

Sub-Team Three: Atmospheric Composition- Mercury

The third sub-team is looking into atmospheric composition. From our initial research, we were interested in looking at the levels of ozone and mercury at varying altitudes throughout the atmosphere. We felt these were extremely relevant to arising environmental issues. Ozone levels are a growing concern in the phenomena of global warming. Mercury poisoning is becoming a health hazard as well, where one hundred percent of Wisconsin’s water bodies are under mercury advisory. As shown in Figure 6, a majority of this mercury enters the waterways from the atmosphere. It is therefore crucial to understand the mercury cycle and be able to detect the localized atmospheric levels.

In order to carry out the ozone experiment, we have been looking at a variety of sensors that can detect ozone and measure appropriate levels that are expected to be found at altitudes throughout the atmosphere up to 100,000 feet. We have recently run into issues with finding a sensor that would be usable, as they are not built to withstand the cold temperatures, or require calibration at known ozone concentrations. After poor communication between companies and hours of research, we have just decided to rule out the ozone experiment to focus more of our attention on monitoring mercury levels.

To measure mercury in water, soil, and air samples, we found that an instrument called a gold trap is used. A gold trap is a quartz tube ¼ inch in diameter and approximately 10 cm long. Within the tube, there is a section of approximately 1 ½ inches that contains gold coated glass beads. As the air sample flows through the tube and gold, the mercury present in the air amalgamates with, or sticks to the gold. After the sample has been taken, the trap is heated to separate the mercury from the gold and the amount present is measured quantitatively. There is also the option of using gold coated sand instead of glass beads. We were fortunate to find a company, Brooks Rand Labs in Seattle, that specializes in mercury sampling. Our contact explained to us a lot of beneficial information about the process. We learned that we want to use glass beads versus sand, as the glass beads are used for air samples, whereas the sand is used for water samples. Once we use the traps to take a sample, we will send our traps to their labs, where they will analyze the traps to find out how much mercury is present.

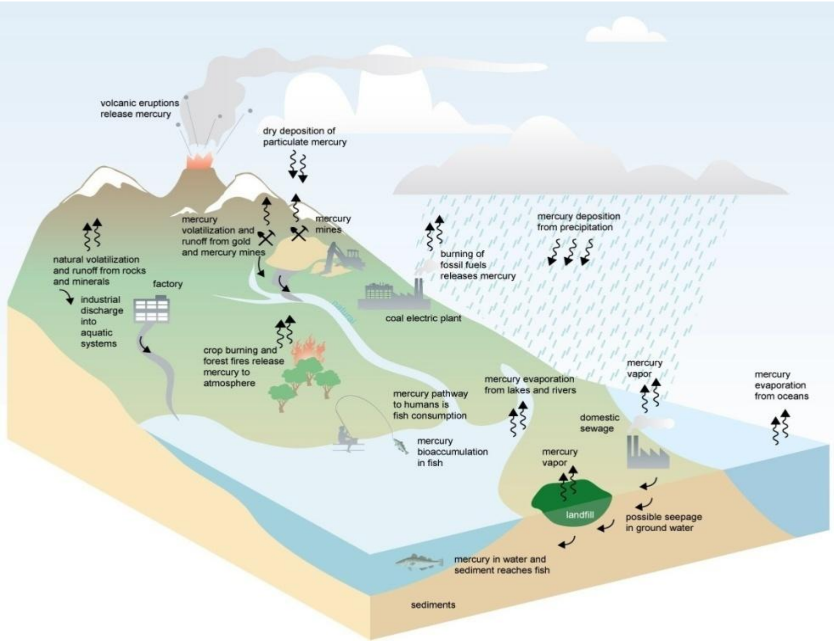


Figure 6- The mercury cycle. A majority of the mercury that enters our waterways comes from the atmosphere.

One of our biggest concerns with using the gold traps is contamination and condensation. We do not want the traps to be exposed to the air until they are ready to be sampled. Similarly, they should not be exposed at any time after the sample is completed either. We must also work on preventing condensation to build up on the traps, as the moisture can alter the effectiveness of the amalgamation process. Since the payload will travel through very cold temperatures and then warmed up again upon descent, we must determine how to keep the traps at or above ambient temperature. Most of the instruments used for measurements are not made to function properly in such varying temperatures either, so the payload must be properly insulated. To keep the traps at an appropriate temperature, we currently plan to use some type of heating-coil or medical pad.

When using the gold traps, there is a set manner in which samples are typically taken, but as ours will travel in a balloon payload, we have had to be creative. We are working on creating parts and a housing unit for the traps in Solid Works and these parts are currently being made at the Rapid Prototyping Center. The design is shown in Figures 7 and 8 on the next page, and can be described as a revolver barrel, where only the inner cylinder rotates to align the appropriate trap. We will take a total of three samples at varying altitudes, with an additional two positions serving as “dummy traps”, or the locations of the cylinder when we are not sampling. These dummy traps serve to isolate the good traps from the elements, so we only draw air through them when desired. We plan to run each sample for fifteen minutes at altitudes of 30,000 feet, 60,000 feet, and 90,000 feet, with one ground sample as well.

Attached at the end on the contraption will be a miniature vacuum, purchased from the Science and Surplus store. We are required to draw a substantial amount of air through the traps, which is why the sample time is so long. The vacuum will be connected with a hose and directed to flow through the appropriate trap only. To do this, we will start with the cylinder in a dummy position, rotate it to the first trap at 30,000 ft., rotate it back to the dummy position until 60,000 ft., and the same for the last trap.

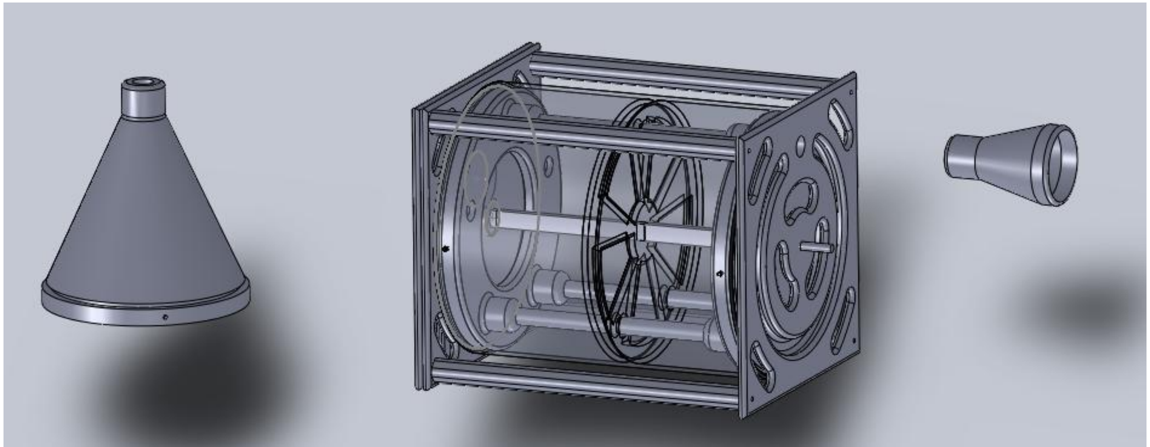


Figure 7: Final design of the mercury assembly. Air enters the system through the left funnel, will be drawn through tubing into the cylinder, and out the vacuum adapter funnel on the right. Only one trap will be tested at a time, and will be sealed off because of the rotating cylinder when not in use.

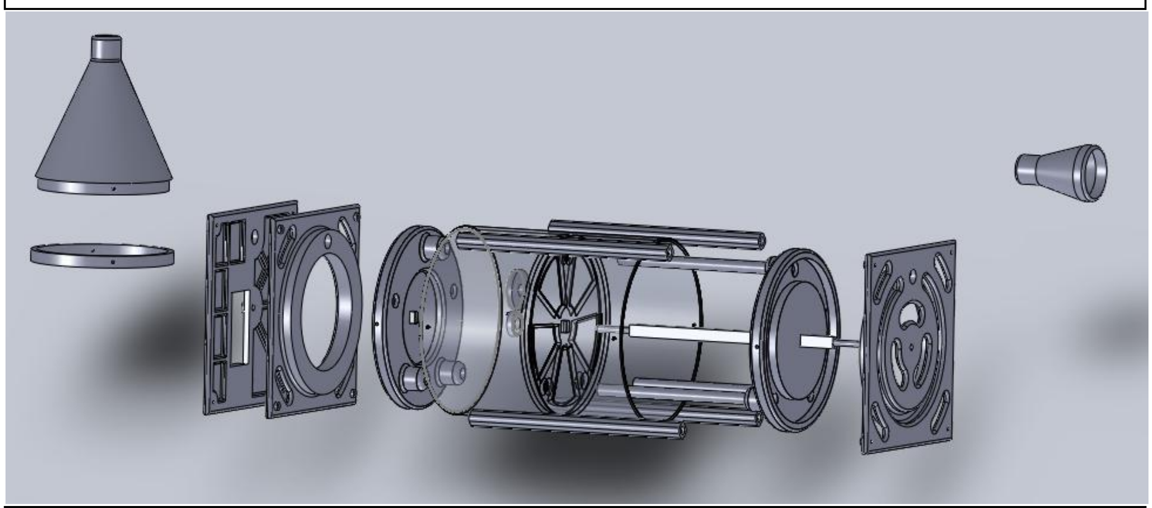
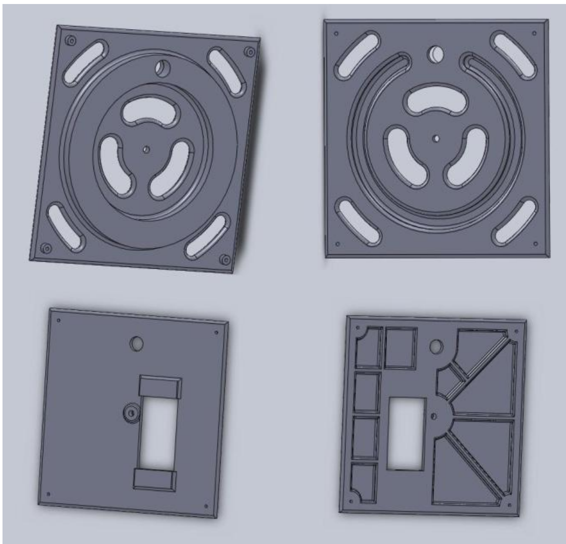


Figure 8: Exploded view of the mercury assembly. The assembly will have 14 parts from the Rapid Prototype Center.

To depict the method of effectively isolating only one trap, Figure 9 below shows a breakdown of parts showing how they fit together. The programming for predetermined altitudes will depend on time, so a time-altitude calculation will be carried out. The rotation will occur from a 180 degree servo motor gear that is meshed with a smaller gear on the cylinder as to allow nearly 360 degree rotation of the cylinder.



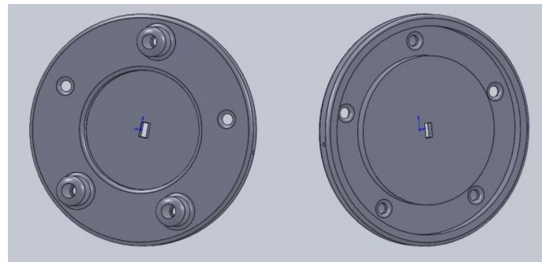


Figure 9: Close-ups of unique parts of the mercury assembly. Top left: end cap slips into the slotted disk to only allow air to pass through one hole at a time. Top right: slotted disk holds the gold traps and secures them to the cylinder. Bottom left: motor plate secures the Servo and holds gears in place.

We do not anticipate finding particulate mercury to be a large problem for us. When using gold traps for air samples, there is a filter typically used to defer any particulate mercury that may be in the air. As our project is a special case for using these traps to sample mercury, we do not believe that there will be enough mercury in the particulate form to alter any measurements or result in any error.

We are very excited to find out what sort of results we will obtain. From our background research of mercury in the atmosphere, we anticipate to find that mercury levels will slightly decrease with altitude. We believe that the traps will give us very accurate measurements, but we also understand that since we slightly manipulated standard manner, we can anticipate some error due to possible contamination. There *will* be some air flow shifting among the traps throughout the flight, along with temperature variation between the samples and no filters will be used. Nonetheless, we anticipate some interesting results.

In conclusion, each team has a set idea of what they find to be truly interesting and beneficial to experiment with, and we are now entering the construction phase. The experimental assemblies/structures are under construction, as will be the overall payload shortly. These coming weeks will be spent testing the apparatuses in a range of temperatures and pressures to ensure a successful launch. All teams are extremely excited about the projects and cannot wait for the upcoming launch.