Colorado Space Grant Consortium

The Effect of Solar and Cosmic Radiation on Viscosity and pH of Pig Blood

THE SPACE PIGS

Grace Kirk, Noah Mauck, Lauren Rickert

Colorado State University

Faculty: Dr. Azer Yalin

2023

TABLE OF CONTENTS

LIST OF FIGURES

SECTION 1: INTRODUCTION

When space travel became a more well-known topic, with it came the topic of what effects space has on the human body. When traveling more than 100,000 feet in the atmosphere, one of the things interacting with the human body is the radiation from both the sun and other cosmic bodies. Therefore, it is important to understand the effects of radiation on the human body, both externally and internally.

It was found that the biggest damage solar radiation has on the body is damage to the DNA in cells. When cells are subjected to solar radiation, the DNA strands can unravel and the body must try to repair the damaged DNA. Sometimes it is able to repair the DNA successfully, but other times the genes are incorrectly repaired and can mutate, eventually leading to cancer [1]. Radiation can happen at any level of the atmosphere including flying on airplanes at the lowest levels of the stratosphere [2]. It is especially important for astronauts to be wary of the amount of radiation that they are exposed to as long-term effects of radiation exposure are increased chances of cancer or mutated genes that can be passed down to future generations [3].

When presented with the task to build a payload that was going to be launched into space, the team spent a long time deliberating over topics and ultimately settled on the idea of blood. While sending human blood up into space was potentially too risky for the scope of this project, it was found that pig blood has similar red blood cell properties to human blood and is much easier to obtain on the basis that pig blood is often used in various cuisines [4]. With the pig blood, the goal of this project was to simulate blood flowing through a bodily system and investigate the relationship between space radiation and the viscosity and pH of the blood.

The goal of this experiment was to model human blood in an artificial pumping environment as it goes up to the edge of space. Human blood was not allowed to be tested outright due to the health risks of obtaining and using it. In order to achieve this model, a pump system was implemented with pig's blood. This system allowed for the continuous movement of the blood in the system so that it would not coagulate like it would outside the human body.

SECTION 2: DESIGN

2.1 BUDGET

The overall cost of the project was $864.84, thus staying under the given budget of $1000. The goal was for the weight of the payload to be underneath 1.5 kg. However, it came in at a total of 1543 g. At the end of the project, just before launch, CSU as a whole was granted a total of 3 kg. The other CSU team, The Bacillus Boys, had a weight of 1443 g. Therefore, the collective weight from both CSU teams was below 3 kg and both teams were able to launch.

2.2 PAYLOAD

Iteration 1 of the box was an 8"x8"x8" cube. It was this size because that was the maximum size that would print on the Prusa i3 MK3S printers. Maximizing size in the first iteration was paramount in order to fit the electronics and pump system. In order to decrease weight later on, the height of the payload was ultimately reduced. Four 6"x6" windows were included in the first design iteration. These ended up being too large. It would be very difficult to insulate the payload with windows this size. It also brought up concerns about structural integrity. These were eventually reduced in size to 2"x2". This design had two ¼" holes in the top and bottom for the flight tubing. This design feature stayed constant throughout each iteration.

Iteration 2 improved on the structural issues from Iteration 1. This design featured a "puzzle-piece" like design to interlock each face. This massively increased the structural integrity of the payload. The size and number of windows were decreased in the second iteration. This helped solve insulation concerns. These changes would remain throughout the next design iterations.

The notable change in iteration 3 was decreasing the overall height of the payload. This was needed because the weight had to be decreased to meet the 1.5 kg limit. Also, the extra height was found to be unnecessary. The bottom piece of the payload was also altered in order to include a spot to fit the battery snuggly into the payload. This led to editing the structural supports on the bottom to make the additional fit. The insulation was integrated fully into this iteration. The two side walls with the windows are double-insulated because the quartz glass is double-paned. If weight was not a concern, each wall would be double insulated. The top piece of the payload is mostly double-insulated. There is a full insulation piece attached to the top of the piece and there are four squares of insulation cut to fit into the structural supports. The flight tube was also fully insulated.

Iteration 4 was the same as the third except that the windows were removed. Getting rid of the windows decreased the weight of the payload and increased the insulation inside the payload. The windows were put there in order to allow UV rays, including UVC, into the payload. After further discussion with the advisors, the windows were deemed unnecessary due to the tubing and reservoir material. These materials would not pass UV rays and thus rendered the windows useless. Without the windows, cosmic rays can still penetrate the exterior and be the variable affecting the pH and viscosity.

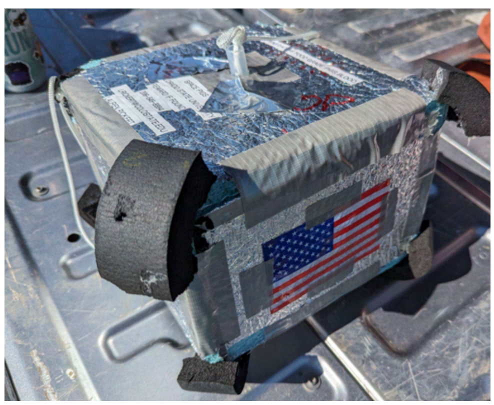


Figure 1 - Fully Integrated Payload

2.3 PUMP SYSTEM

The following figure shows the early stages of the pump system.

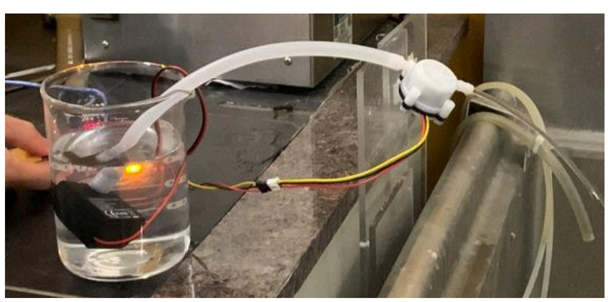


Figure 2 - Early Stage Pump System

The pump is a 12V DC submersible aquarium pump. This pump advertises a 3-meter pump head which equates to about 4.26 psi of differential pressure.

The code was written to alter the pump speed based on the volumetric flow rate measured by the flow meter. The flow would be measured once every second due to manufacturer specifications. For a proper comparison of pressure drop to viscosity, the flow rate must be constant. The following equation shows the relationship between viscosity and pressure loss

$$\Delta p_{lam} = \frac{32\eta L}{D^2} \cdot \overline{v} \tag{1}$$

where Δp_{lam} is the pressure drop from a laminar flow, η is the dynamic viscosity of the fluid, L is the length across the differential pressure is measured, D is the diameter of the pipe, and $\overline{v}$ is the volumetric flow rate.

2.4 BLOOD RESERVOIR

For iteration 1, a small beaker was used to submerge the pump into the liquid. This container is shown in Figure 2.

For iteration 2, a container was ordered on Amazon (Item No. 3) that was originally designed for a computer water cooling system. It had a lid that could be screwed on and off to fill and empty it and it had three ports for inlets and outlets. The plan was for two of those ports to hold the inlet and the outlet of the tubing, and the third port would hold the wires of the pump and temperature sensor. This would allow for the wires of the pump to exit the reservoir and the temperature sensor to be in contact with the blood. Once the container came in, the fit of the pump was too tight for the tubing to connect and fit through the ports.

The third and final iteration of the box was custom-made from ¼” acrylic glass. It was designed to have four ports: two ports for the inlet and outlet of the tubing, one port for the pump wires, and one port for the temperature sensor. The acrylic was cut using a table saw and ground down on a vertical grinder to ensure a tight fit along all the sides of the box. The pieces were then glued together using JB Weld Plastic Bonder epoxy and watertight sealed with LOCTITE clear silicone.

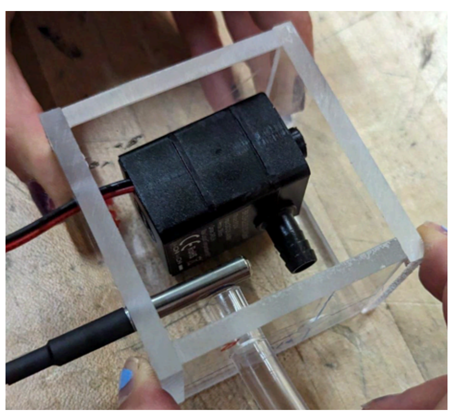


Figure 3 - Third Iteration of Blood Reservoir

2.5 FULLY INTEGRATED PAYLOAD

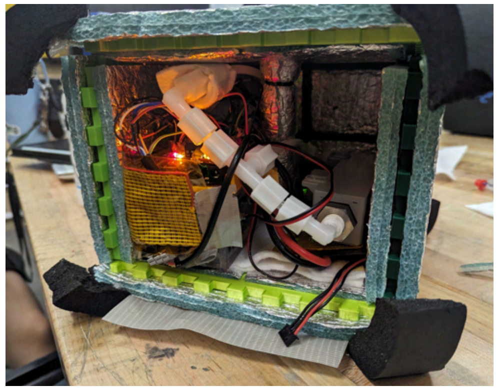


Figure 4 - Fully Integrated Payload Electronics View

The fully integrated payload has the reservoir, Arduino, pump, flowmeter, tubing, pressure sensor, battery, heaters, pH probe, and flight tube within the payload design. It also includes the washers and paper clips that keep the flight tube in place as well as foam on the corners to help absorb the impact when it lands on the ground.

SECTION 3: TEST PLAN AND RESULTS

3.1 COLD TEST

For test 1, the temperature inside the cooler was 0.48°C. The payload was inside the test for 30 minutes. The data file showed corruption when it was checked after the test; however, the pump and other electronic systems were functional.

For test 2, the temperature inside the cooler was -48.31°C. The payload was in the cooler for 20 minutes before being taken out and checked. During this time, smoke was observed coming out of the top and the payload was very hot. Upon opening the payload, it was observed that the pins on the underside of the SD card reader had pierced the heater and short-circuited as shown in Appendix B.12. This is what led to the excess heat and the smoking. The heater, SD card, and SD card reader no longer worked after the test and were all replaced. The interface between the electronics, heater, and reservoir was redesigned.

For test 3, the temperature inside the cooler reached -52.60°C. The payload stayed inside the cooler for a total of 1 hour and 50 minutes, with it being checked at the 20 minute and 1 hour marks. Overall, nothing in the payload malfunctioned or froze and the system continued running for the entire duration of the test. When inspecting the data afterwards, it was found that everything collected data as it should, but that the flow meter showed zero for several seconds at multiple points throughout the entire testing period. The water in the reservoir did not drop below the target temperature of 15 degrees Celsius to start the heaters. The battery ended at 11.7 V or 3.9 V per cell.

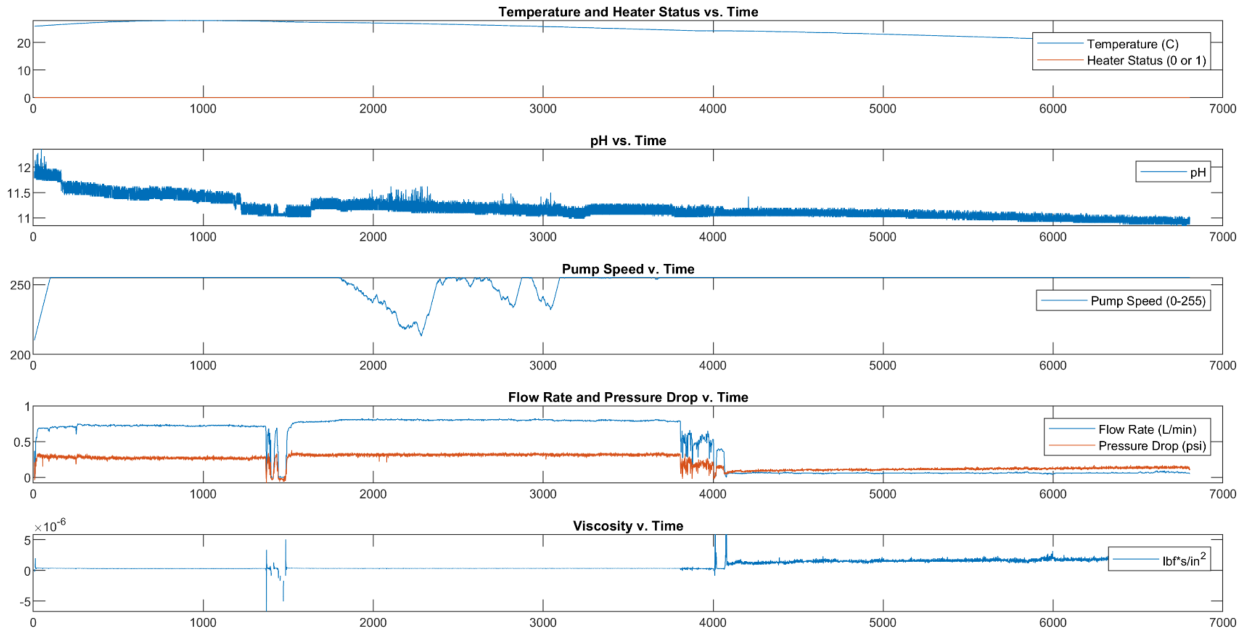


Figure 5 - Cold Test 3 Results

For test 4, the temperature inside the cooler was around -29°C. The temperature sensor for the dry ice was placed against the edge of the payload this time rather than at the very bottom of the cooler which is why the temperature is higher than the previous tests. Dry ice was placed on the sides of the payload as well as two pieces on top in order to attempt to simulate a lower temperature. The payload was inside of the cooler for 2 hours and 30 minutes. It was checked at 30 minutes, 1 hour, and then at the very end when it was taken out to make sure the pump was still running. When it was taken out at the end, the SD was checked for data and everything was running as it should as well as writing data as it should.

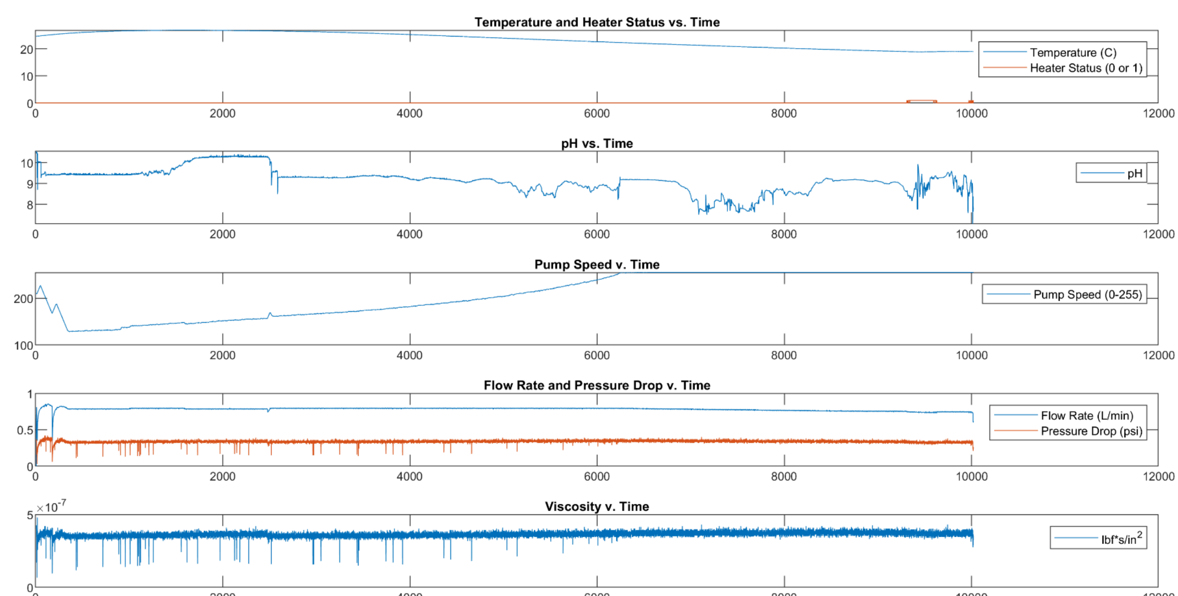


Figure 6 - Cold Test 4 Results

The figure above shows the results from test 4. This test was completed after the initial vacuum test. The pH data shows that the sensor is not working properly. This is explained in greater detail in Section 3.5. However, all of the other data showed successful payload functionality. The pump speed increased over time to maintain the flow rate of 0.8 L/min. The pump speed had to increase over time due to the voltage of the battery decreasing over the duration of the test. The heaters turned on and successfully heated the liquid in the reservoir back to the target temperature two separate times.

3.2 DROP TEST

For test 1, the payload was dropped from 18 feet onto a hard surface. The structure of the payload and most of the components inside stayed intact. The only things that came loose were the micro SD card that popped out of the SD reader and the wire housing for the temperature gauge. The battery also became unplugged upon impact. Because the battery came unplugged upon impact, the payload stopped operating.

For test 2, in order to keep the battery from unplugging, the connection was duct taped. This was successful, however, this drop test led to a wire being unsoldered between the Arduino and the switch. This meant that the payload stopped operating and no data was collected after the impact. The payload itself was not damaged and was kept intact.

The wire was resoldered for test 3. Upon impact, the switch was flipped back to the off position. This, again, led to the system failing to run after impact. Data was collected up until impact, however. For launch day, the switch will be duct taped to the on position in order for it to not turn off on launch. If the switch is flipped to the off position upon impact when landing, it will not hinder the experiment because the target data will have already been collected in the air. These three tests show the impact will cause no structural damage or leaks within the payload.

3.3 WHIP TEST

The first whip test was successful. The payload was whipped around in a field for about 45 seconds and all the components remained intact with no leaks. The flow sensor read zero at a couple of instances which could be due to potential air bubbles in the system. However, this could have also been due to the G-forces. Figure 7 shows that the pressure drop follows the flow rate which means that the system was intact and in sync for the entirety of the test.

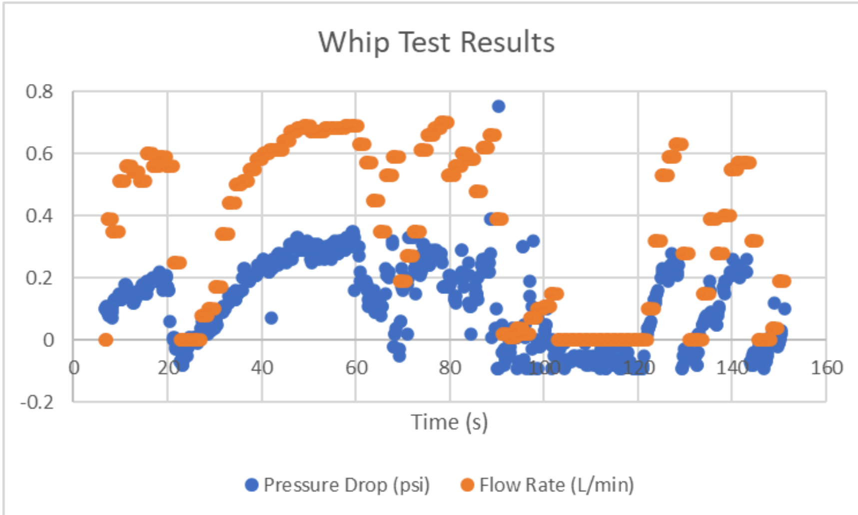


Figure 7 - Whip Test Results

3.4 UV TEST

A baseline test was done with no added UV light introduced to the system. The system for this test was just the pH probe with blood in it. The system ran for about an hour and data was collected. The pH stayed very constant throughout the duration of the test.

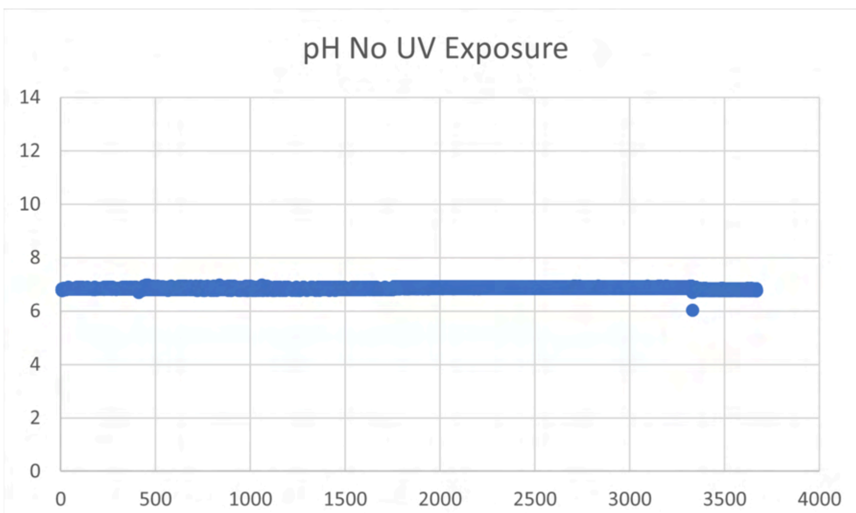


Figure 8 - Baseline UV Test Results with no UV

A second test was run with a UV light bulb shining on the pH probe. Data was collected for an hour. The light bulb supposedly had UVC leaking from it, however, after the test, the wavelengths were determined to be around 320 nm. This means that it was not producing light in the UVC range which is what the goal of the test was, so this test was deemed unsuccessful. After this test, it was decided due to other factors mentioned earlier that UVC was no longer going to be intentionally present in the system. The main independent variable was going to be cosmic rays. Due to this, no further UV testing was performed.

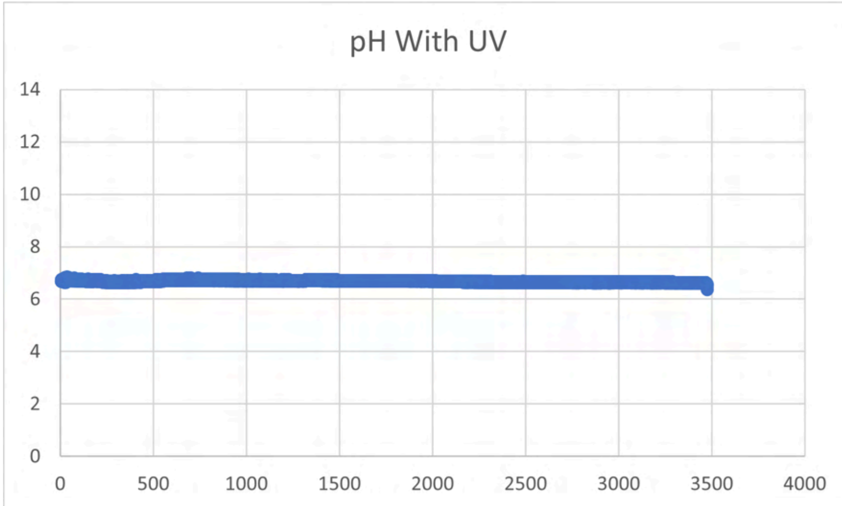


Figure 9 - Baseline UV Test Results with UV

3.5 VACUUM TEST

The first vacuum test was fairly successful. The system was inside the vacuum chamber for 3 to 4 minutes at 4 torr which is about 0.5% of an atmosphere. The only mishap that occurred was slight leaking in one of the corners of the reservoir. This was promptly fixed with added epoxy and sealant. The pH probe was also tested separately under the same conditions. The air inside the cap expanded causing the cap to slowly come off the probe and finally pop off. The cap stayed on the probe at about 1% of an atmosphere. Once the cap popped off, there was bubbling seen under the probe which was assumed to be the water inside the probe. The vacuum chamber was brought back to atmospheric pressure and the probe was taken out and inspected. It was found that something else had leaked. There was a gel capsule inside of the pH probe that had erupted and spilled. The gel was potassium chloride which is used as a pH comparison as it is a pH of 7.0. The pH probe now sometimes gives reasonable and consistent results and sometimes gives erratic results.

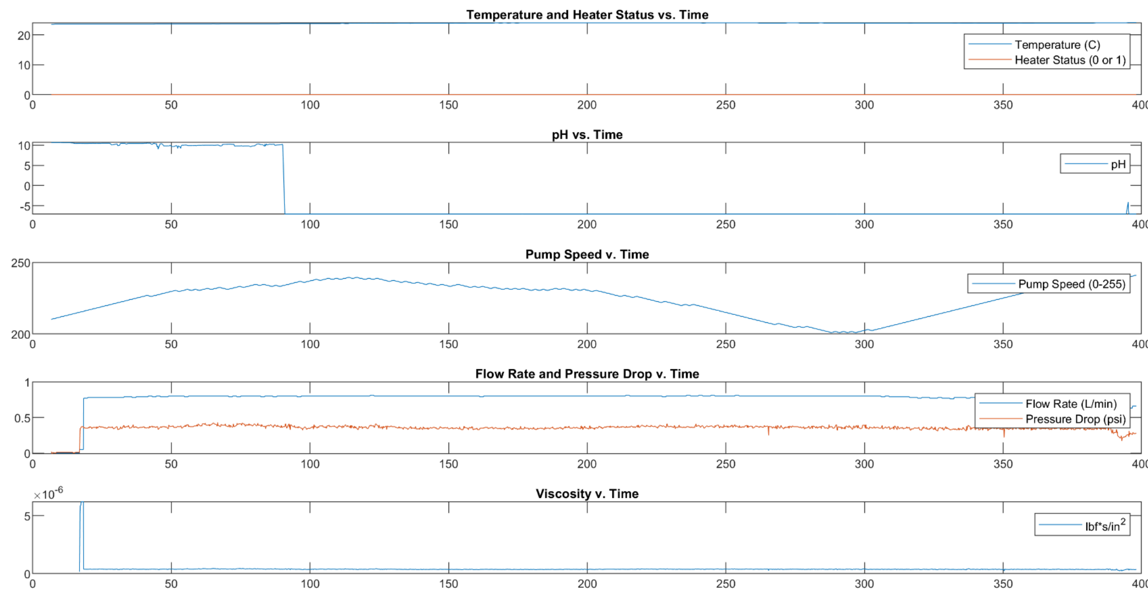


Figure 10 - Vacuum Test Data

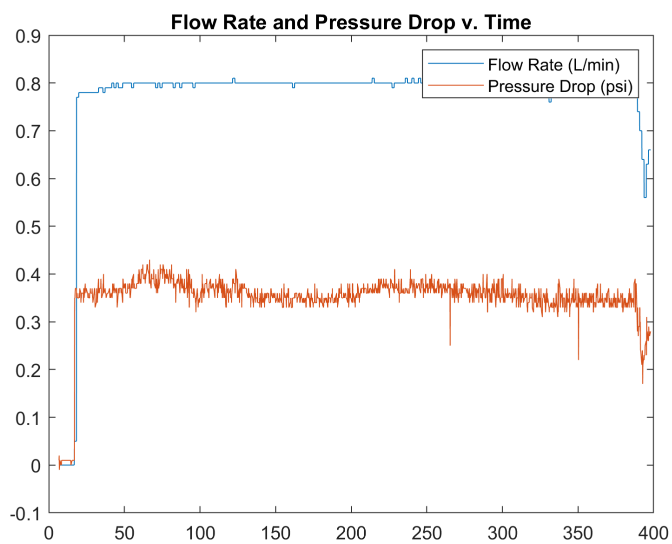


Figure 11 - Vacuum Test Data cont.

The data shows that the pressure of the flow and the flow rate follow the same trend and path which indicates that the lowering of the pressure did not affect those instruments. The pressure sensor had small spikes as it was put under vacuum which will need to be taken into account when looking at the data from the flight.

SECTION 4: EXPECTED RESULTS

4.1 TEMPERATURE

In order to determine if space radiation has an effect on the viscosity of blood, the temperature throughout its journey must stay constant. However, it is highly unlikely that the temperature will stay constant throughout the entire experiment due to the harsh environment it will be put in. To compensate for this, models were created to determine how temperature affects the viscosity of blood, and subsequently, the pressure drop measured. These models will be discussed in further detail in Section 4.2. A 2.5 hour fundamental test was performed to give baseline data results. This will be helpful in the analysis of the actual flight data. This data is shown in Figure 12.

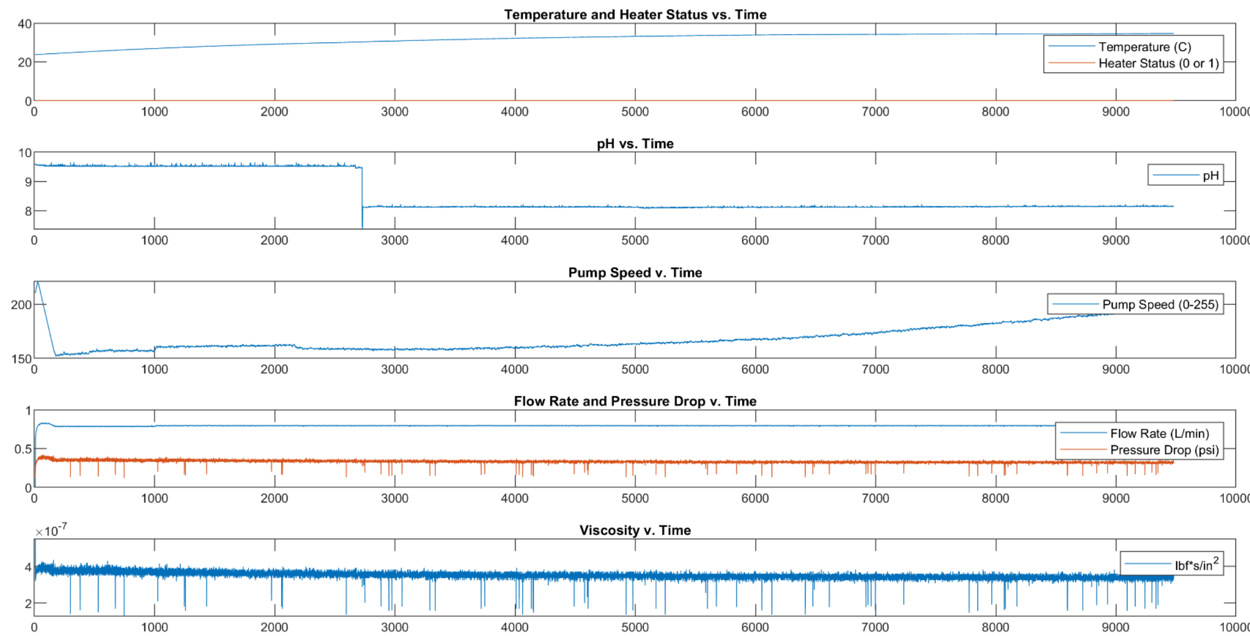


Figure 12 - Fundamental Test Graph

4.2 PRESSURE DROP

A total of three models were used to predict the changes in pressure drop due to temperature effects. Again, the goal was to have the pressure drop be a direct result of the change in viscosity. This way, any change in viscosity would be measurable from the pressure transducer. This relationship is shown in Equation 1. Because the temperature was going to change in flight, these models were created. These models were constructed using values like length, diameter, flow rate, etc. from the actual payload.

The first model created was the “2% Model”. From Cardiovascular Physiology Concepts by. Richard E. Klabunde, PhD, an inverse relationship was found between temperature and viscosity of blood. Viscosity increases about 2% for each degree centigrade decrease in temperature [5]. Data was generated from the nominal viscosity of blood at 37 Celsius (0.0045 Pa*s). As the temperature increased by one degree Celsius, viscosity was decreased by 2%. As the temperature decreased by one degree Celsius, viscosity was increased by 2%. The data was graphed and an equation was gathered.

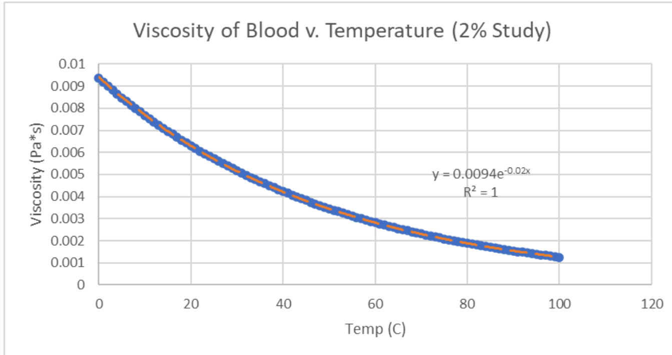


Figure 13 - Temperature v. Viscosity (2% Model)

This equation was put into EES where the independent variable was temperature and the dependent was viscosity. Viscosity was then used to calculate the Reynolds number and, subsequently, the pressure drop. The temperature ranged from 0 to 100C with 300 data points. An equation can be generated from this model to compare the results from flight. The flow is expected to stay laminar.

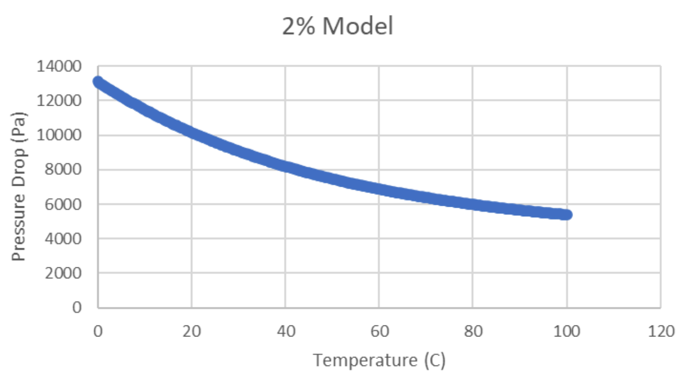


Figure 14 - 2% Model Pressure Drop

The next model created was the “Aqueous-Glycerol Study Model”. The National Library of Medicine states “An aqueous-glycerol solution is commonly used to mimic the viscosity of blood”. They also state that “ [with] a mixture ratio of 49 mass percent of aqueous-glycerol solution, the [viscosity] controller can mimic a viscosity range corresponding to a hematocrit between 29 and 42% in a temperature range of 30-42°C” [6]. Though the temperature was a bit high in this study, a model was created anyway. This is partly due to the fact that there is no known data because blood is usually only inside the body. A 50/50% mass split would be easy to calculate the viscosity dependence of temperature because studies have already been conducted. Equation 2 comes from Yen-Ming Chen and Arne J. Pearlstein from the Department of Aerospace and Mechanical Engineering at the University of Arizona [7].

$$\mu(T) = De^{E/T^3+FT+G/T} \qquad (2)$$

A table of constants from their text was used to formulate the equation. This equation was put into EES where the independent variable was temperature and the dependent was viscosity. Viscosity was then used to calculate the Reynolds number and, subsequently, the pressure drop. These results are shown in the figure below.

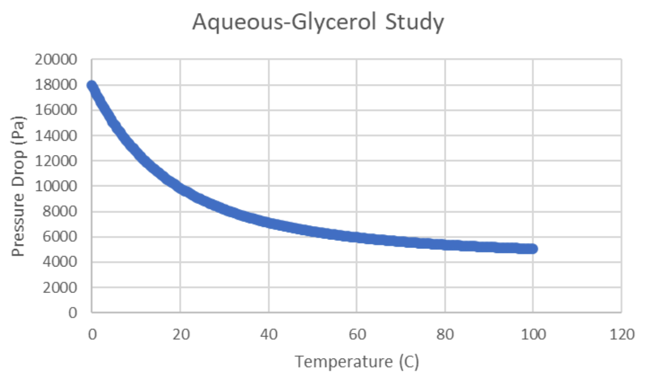


Figure 15 - Aqueous-Glycerol Study Pressure Drop

The third and final model is exactly like the previous, but the values were obtained from thermodynamic properties of water and glycerol. Also, the correct mass ratio of 49 mass percent of aqueous-glycerol was used. The three step liquid viscosity blend equations were used to correctly weight the two liquids into a mixture [8]. These were, once again, plugged into EES to graph. The results are shown in the figure below.

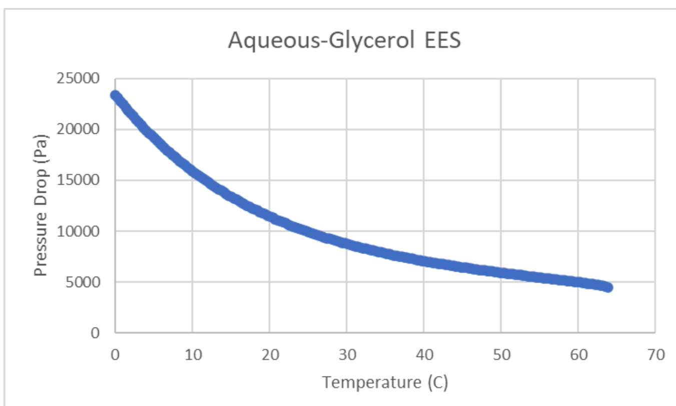


Figure 16 - Aqueous-Glycerol EES Pressure Drop

These three models differ from one another because of the assumptions they are based on. However, they all share the same general shape and trend. The graph with all three models is shown below.

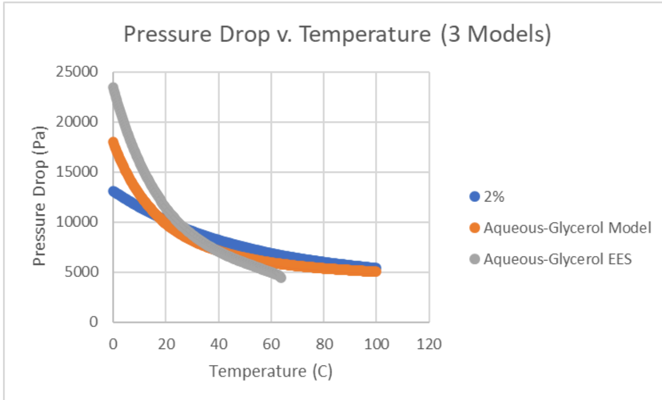


Figure 17 - Pressure Drop v. Temperature (Models)

These three models will be beneficial in analyzing the flight data. If the temperature were to fluctuate, the change in pressure drop would be known to be because of the temperature dependence on viscosity, not the effects of space radiation.

SECTION 5: LAUNCH AND RECOVERY

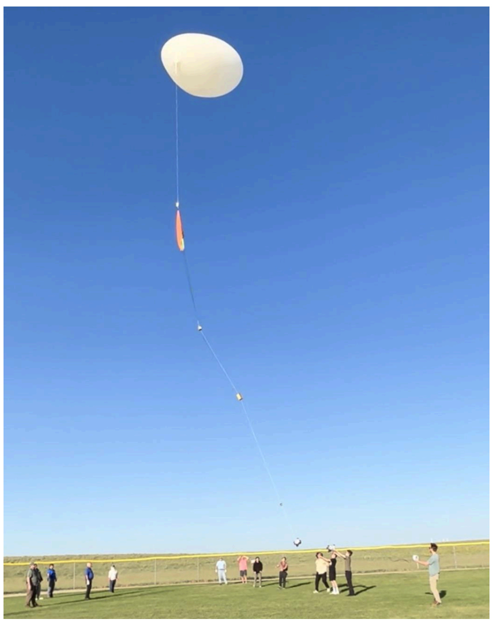


Figure 18 - Balloon Launch

The balloon launched at 7:08 am. The balloon climbed for just over 49 minutes before bursting and starting its descent back down. The payloads landed back down at 8:48 am where recovery then took place. The payload was successfully recovered after launch. There was no damage visible to the outside, and no leaks were observed. If there were to be leaks, safety measures were put in place for proper cleanup. The payload was still running and collecting data when it was found.

Upon opening the payload, a few small leaks were observed. However, these leaks were contained within the payload due to the absorbent material and the tight seal from all six sides. Other than these leaks, no damage was observed on the internals of the payload.

SECTION 6: RESULTS AND ANALYSIS

6.1 DATA

On July 29, 2023 EOSS Flight 345 reached an apogee at 102,383 feet. EOSS Flight 345 trackers ran for a total of 2 hours and 39 minutes. EOSS trackers were turned on 24 minutes before liftoff. The experiemntal payload successfully collected data for 2 hours and 19 minutes. In total, 40,076 data points were collected. This means the payload successfully collected data for the entire duration of flight. Upon recovery, the device was still on, functioning, and recording data. The significant data plots are shown in the figures below.

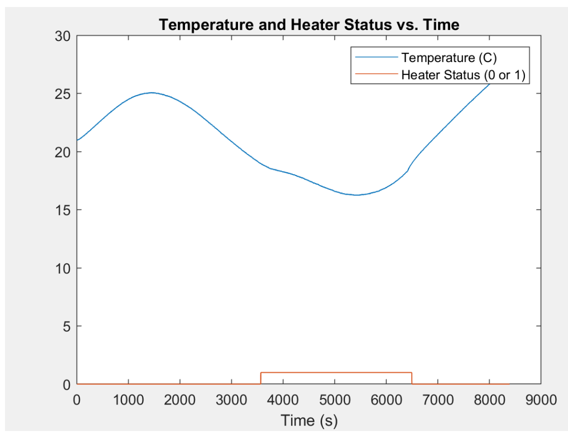


Figure 19 - Flight Data: Temperature and Heater Status v. Time

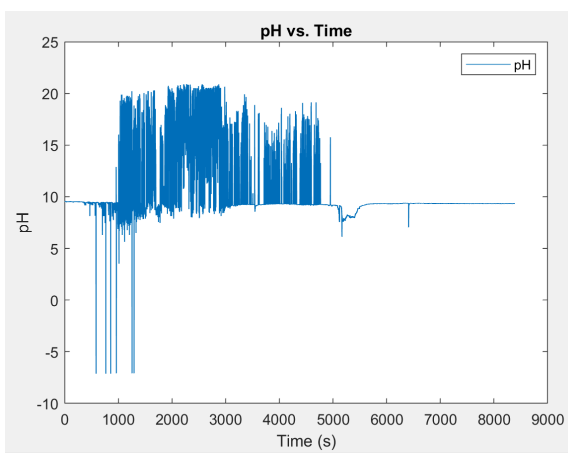


Figure 20 - Flight Data: pH v. Time

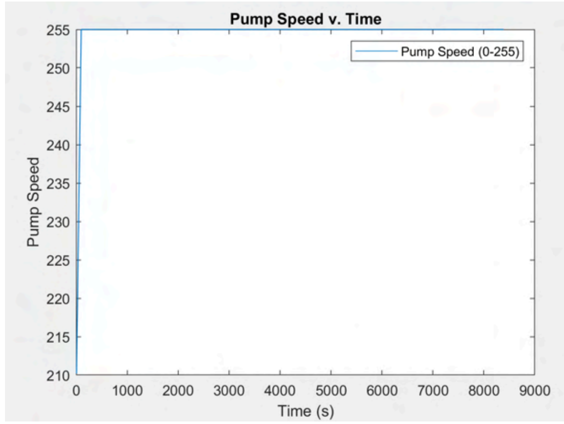


Figure 21 - Flight Data: Pump Speed v. Time

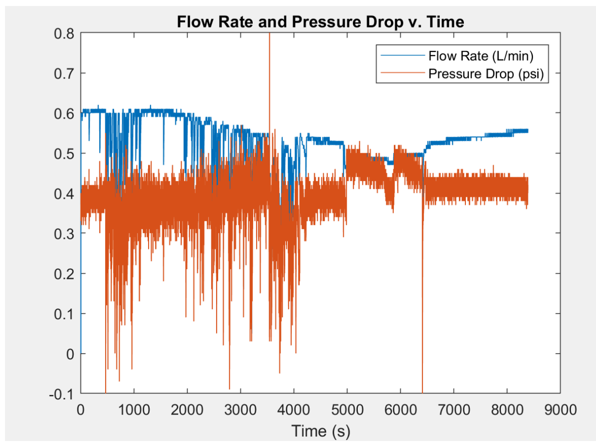


Figure 22 - Flight Data: Flow Rate and Pressure Drop v. Time

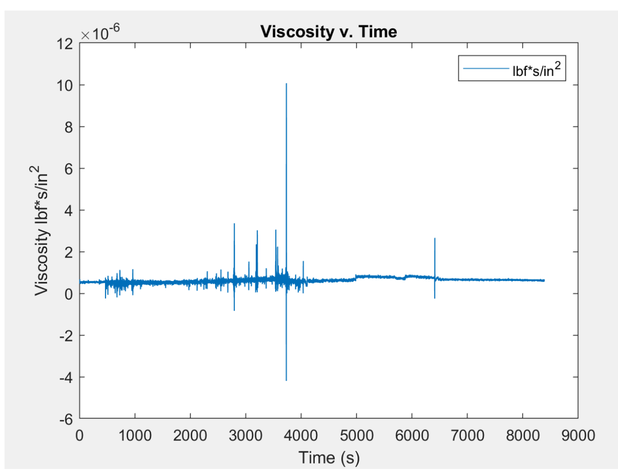


Figure 23 - Flight Data: Viscosity v. Time

6.2 DATA ANALYSIS

Temperature

The temperature of the blood varied with altitude as seen in Figure 19. The blood warmed up as the pump system ran and the payload was still on the ground or in the lower atmosphere. The temperature started to drop as time went on and the payload rose higher into colder environments. The heaters turned on when the blood hit 18 degrees Celsius as they were supposed to. The heaters were able to quell the lowering temperatures of the blood a little bit as seen in the less aggressive slope between the times of 3500 and 5000 seconds. Once the balloon popped and the payload began to fall back to Earth, the temperature began to rise again. The heaters worked successfully and the temperature stayed within the range of 16 and 27 degrees Celsius.

pH

The pH data in Figure 20 shows the blood had a pH of about 10 at the beginning and the end of the flight. The pH fluctuated erratically as the payload rose into the upper atmosphere. This is a sign that the pH probe was not working properly.

Pump Speed

As seen in Figure 21, the pump speed immediately jumped to the fastest it could get to. This happened because the payload was calibrated to move water, and during the actual flight, it was moving blood which is slightly more viscous and thick. This would require more power to be used to move the blood as much as the water was moved. In order to reduce cleanup, blood was never tested inside the entire system before launch. With water in the system, the target flow rate was 0.8 L/min which was continually achieved during testing. If this experiment was to be run again, the payload should have run blood through the system to obtain an adequate target flow rate.

Flow Rate and Pressure Drop

The flow rate was relatively constant between 0.5 L/min and 0.6 L/min. However, in order to accurately deduce that the viscosity change was due to the effects of radiation, this had to have been constant. The flow rate and pressure drop trended in the same direction as one another which would indicate that the system was measuring properly. Because so much data was collected, there were a few anomalies which are shown by the spikes in the graph. This could be due to g-forces, air in the system, leaks, and/or sensor malfunction. However, in each case, a steady trendline can be seen.

Viscosity

The viscosity is shown to be generally constant with a slight increase from 5000 to 6000 seconds followed by a short decrease. Between 5000-6000 seconds, the temperature of the system was decreasing. From the models, this would mean the pressure drop would decrease which is not what the flight data shows. This could be due to the fact the flow rate was decreasing during this time. However, the temperature was also decreasing from about 2000 seconds to 5000 seconds. In this time the pressure drop followed the trend of the models and increased. But, the viscosity was relatively constant during this time. Because of too many dependencies, flow rate fluctuations, and temperature changes, it cannot be accurately concluded that the changes in viscosity shown were from the effects of space radiation.

SECTION 7: CONCLUSIONS

7.1 LESSONS LEARNED

This project is a unique experience, in that every member of the team gets to be a part of every process and decision that is made throughout the duration of this internship. When it comes to finding components for your payload, sometimes it can be very challenging to find the exact parts and sensors to fit the dimensions, precision, and cost dictated by your project. This can mean getting something really expensive that does not perfectly fit what you want. However, that may be all you can get. Do not stress too much about this. You can also ask your mentors for help looking for specific sensors and parts because they know the best websites and catalogs for these things. Remember that the scope of this project is small and you are only biting off a small chunk of the larger cookie. Even if things do not go exactly as planned, remember that you accomplished something, and that is something to be proud of.

Embrace the process and do not be afraid to fail. The best learning experiences from this project were when things didn't go as planned. This is okay and to be expected. Failure is a part of the learning process. Have fun and embrace the differences that this project throws at you. Do not be afraid to ask the graduate students and advisors for help with any step of the process. While they may seem busy with the research they are doing, they will always take time to help you, whether it be helping find a particularly hard-to-source component or guidance on next steps. They have much more experience with experiments in general, but they also have mentored this program in the past and know how to fix certain problems. Work efficiently but also know that you have plenty of time to get everything done, so do not get too stressed out. That being said, it should be your goal to start testing as soon as possible. This will give you time to fix any issues that may arise. Organization is also key. Making a timeline of the entire program duration and estimations on when certain things should get done can really help streamline the process, especially once it gets closer to launch day.

7.3 ACKNOWLEDGEMENTS

Special thanks goes to Steve Schroyer and the Colorado Custom Meat Company for being incredibly helpful providing the pigs blood for testing and the final flight. Thanks to the CSU Meat Sciences Department, specifically Kyle Harrington, for their willingness to help us find anticoagulants. We would also like to thank Dr. Azer Yalin, Jacob Gotfried, and Seth Antozzi for their mentorship and help throughout the project. Thanks to Bernadette Garcia of NASA Colorado Space Grant Consortium for guidance and tips throughout the summer and running the program. We also want to thank the Bacillus Boys (Tabor Horrigan, Luke Crawford, and Nick Clark) for their comradery throughout the summer. And finally, thank you to Kevin Ridgeway for his good spirit, thoughtful questions, and access to his hot glue gun.

SECTION 8: APPENDIX

8.1 APPENDIX A

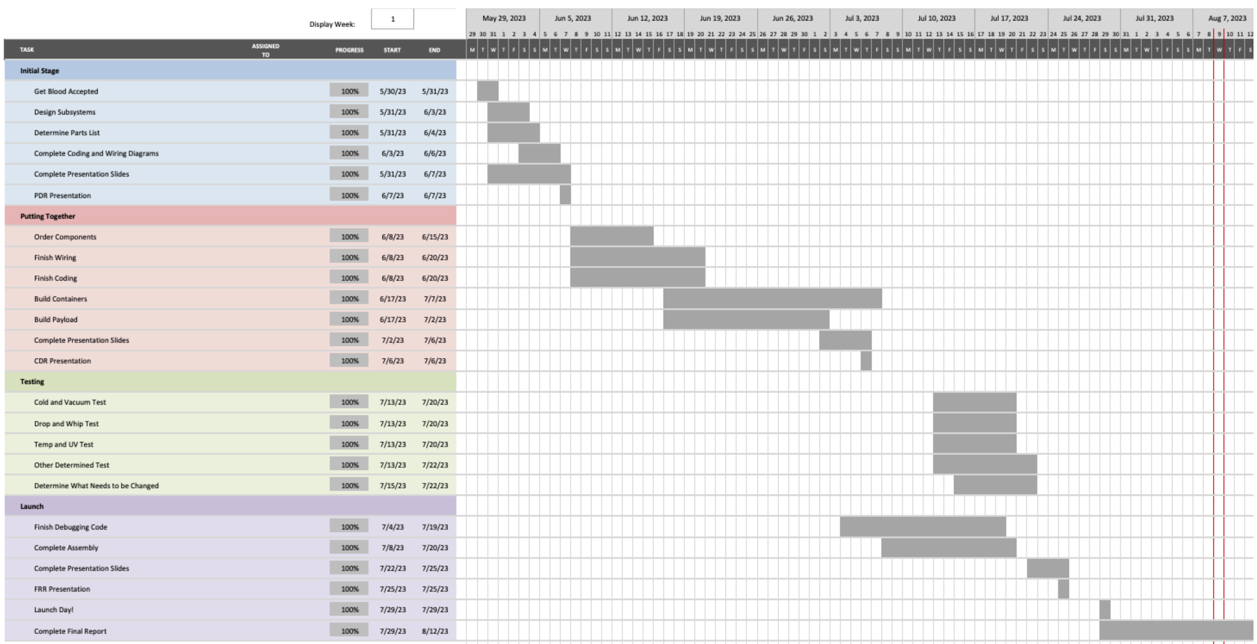
A.1. Bill of Materials

PART NO.	ITEM NAME	DESCRIPTION	DISTRIBUTOR	LEAD TIME (SHIPPING)	COST PER UNIT	QTY.	TOTAL COST	LINK
1	Anticoagulant	Dextrose, Monohydrate, FCC Grade, Powder	Lab Alley	24-48 hours	25	1	25	-
2	Batteries	CNHL 2200mAh 3S Lipo Battery 40C 11.1V lipo Battery with XT60 for RC Airplane RC Quadcopter RC Evader BX Car RC Truggy RC Truck Boat(2 Packs)	Amazon	2 days	37.9	1	37.9	-
3	Container for blood	Cylindrical Water Cooling Tank,50mm Transparent Fast Cooling Water Tank,POM Material,Heat Exchanger Water Cooling Reservoir Radiator for PC Computer Water Cooling Radiator	Amazon	2 days	14.48	1	14.48	-
4	Data Logger	Micro SD Card Storage - pack of 2	Amazon	2 days	6.71	1	6.71	-
5	Dry Ice	From King Soopers	King Soopers	0 days	3.92	24	94.08	
6	Fittings	3/8" OD quick connectors - 16 pcs	Amazon	2 days	15.32	1	15.32	-
7	Fittings #2	Plastic	McMaster-Carr	1 Day	22.32	1	22.32	-

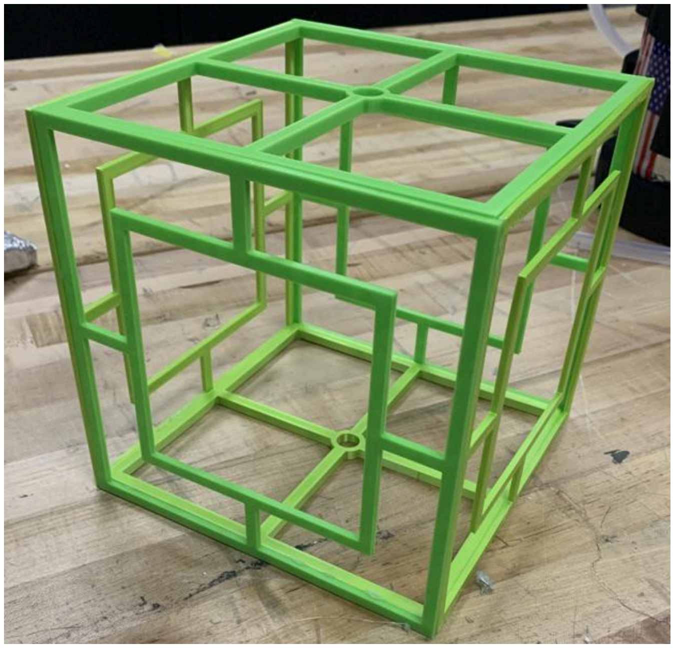
		Compression Tube Fitting for Water						
8	Flow meter	Water flow sensor- 1/4" diameter	Amazon	2 days	10.93	1	10.93	-
9	Glass	Nanotech UV Quartz Plates	Amazon	8 days	19.5	4	78	-
10	Magnetic Stirring Stage	ANZESER Magnetic Stirrer Magnetic Stir Plate 3000RPM Lab Stirrers with Stir Bar Max Stirring Capacity 3000mL Magnetic Mixer (No Heating)	Amazon	2 days	27.15	1	27.15	-
11	Micro SD Card	SanDisk Flash 32 GB microSDHC	Amazon	6 days	7.99	3	23.97	-
12	pH probe	GAOHOU PH0-14 Value Detect Sensor Module + PH Electrode Probe BNC For Arduino	Amazon	2 days	32.7	1	32.7	-
13	Pressure Sensor	Differential Pressure Transmitter for Liquids	McMaster-Carr	unknown	405	1	405	-
14	Pump	12V water pump	Amazon	2 days	13.62	1	13.62	-
15	Temperature sensor	Gravity: Waterproof DS18B20 Temperature Sensor Kit	DigiKey	14 days	13.7	1	13.7	-
16	Tubing	Clear pvc tube - 10ft L x 0.25" ID x 3/8" OD	Amazon	2 days	5	1	5	-
17	UV Light	BAIMNOCM UVC Light Bulb	Amazon	6 days	22	1	22	-

		Germicidal UV Sanitizer Light Bulb 25 Watt 254nm Ozone Free						
18	Zorb	Zorb Super Absorbent Fabric (Made in USA) (1 Yard, 30" wide)	Amazon	6 days	16.97	1	16.97	-

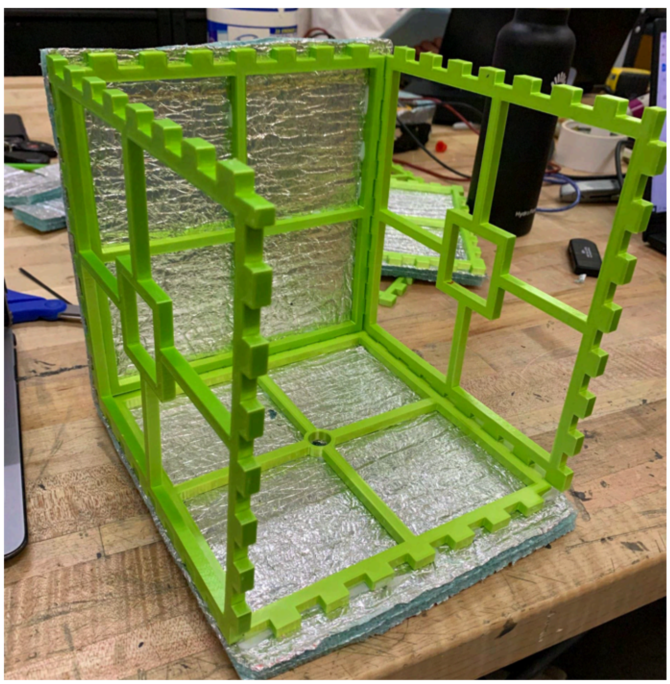
8.2 APPENDIX B



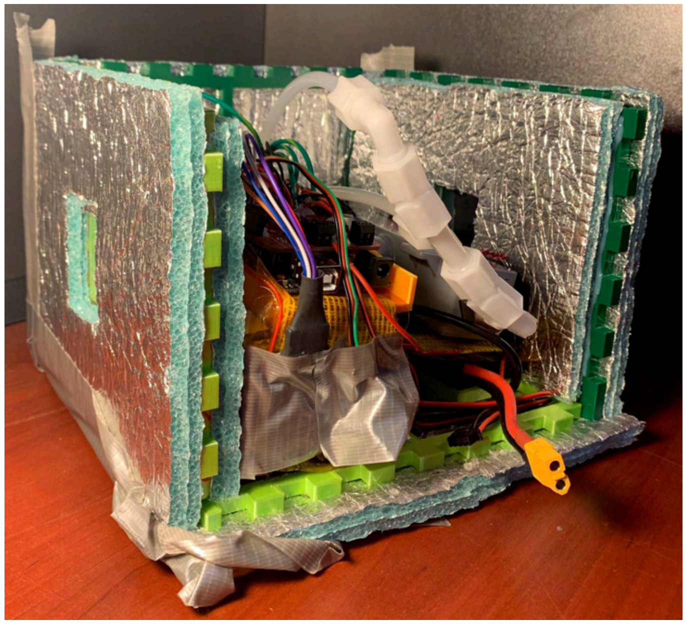
B.1. GANTT Chart



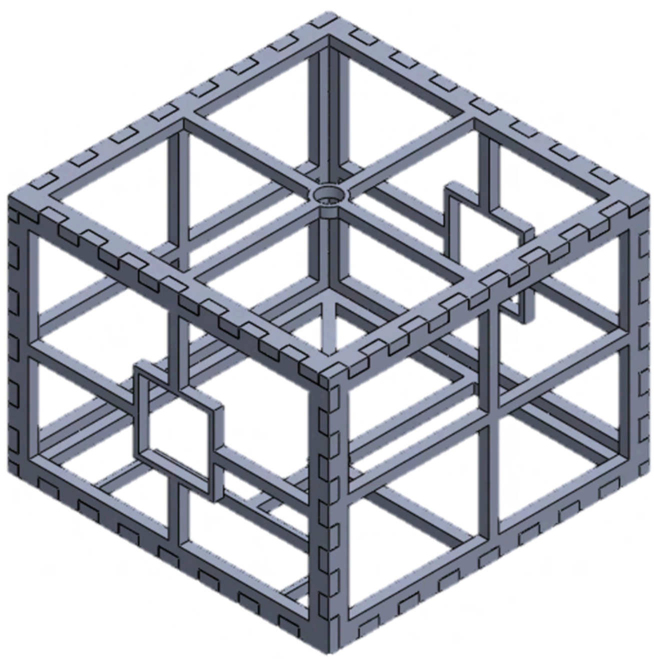
B.2. First Iteration Payload Structure



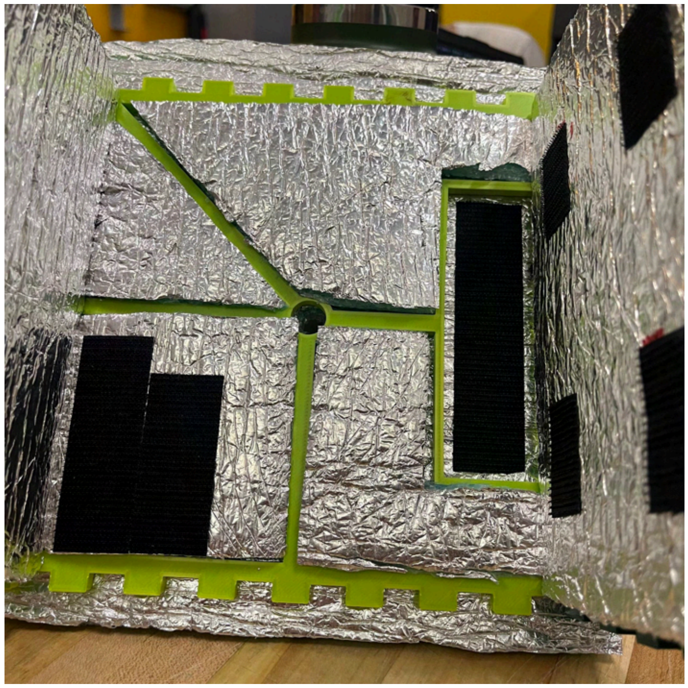
B.3. Second Iteration Payload Structure



B.4. Third Iteration Payload Structure

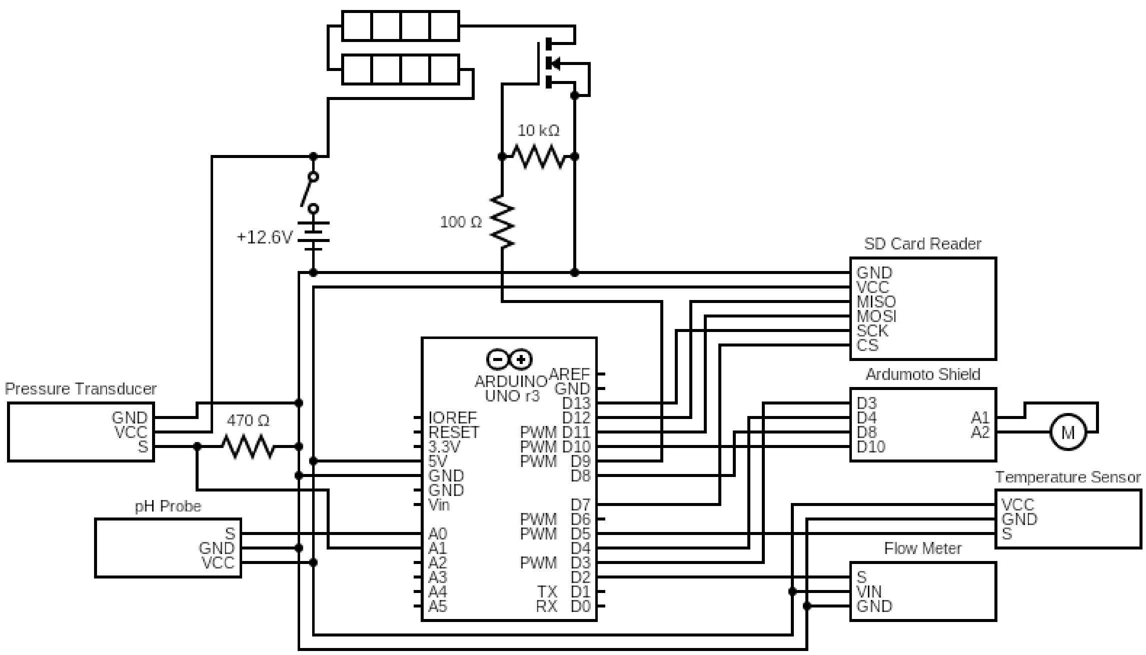


B.5. Third Iteration CAD Model

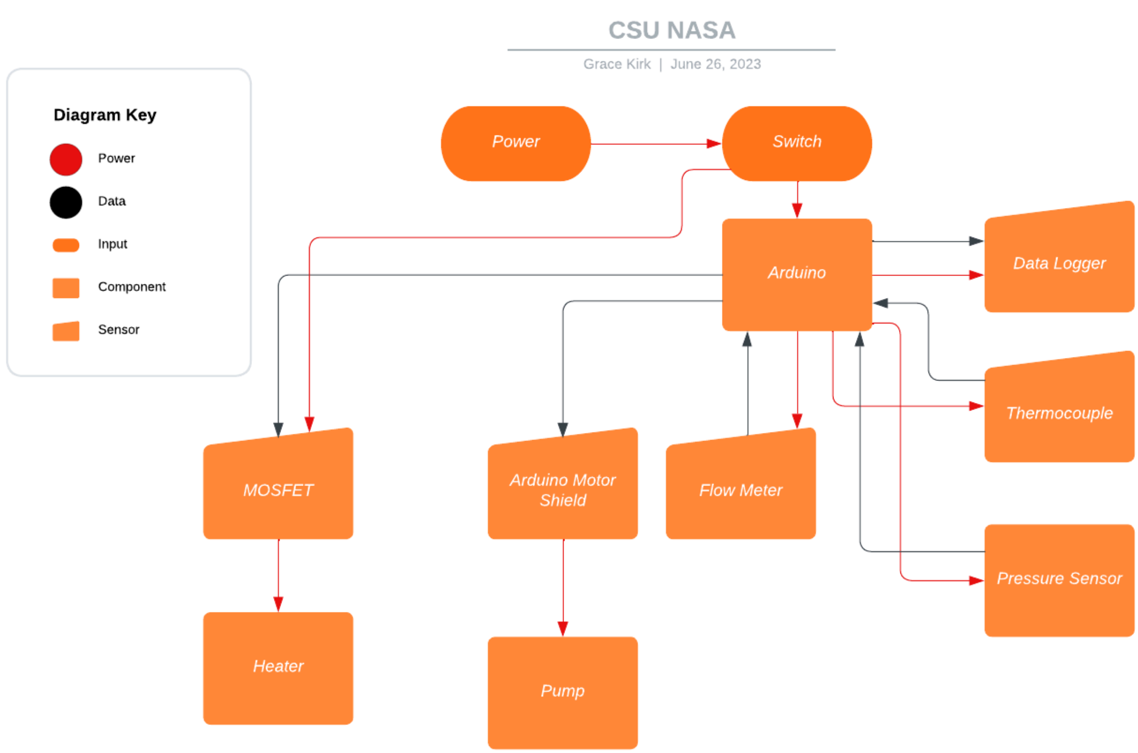


B.6. Bottom Piece of Third Iteration

B.7. Top Piece of Third Iteration with Flight Tube

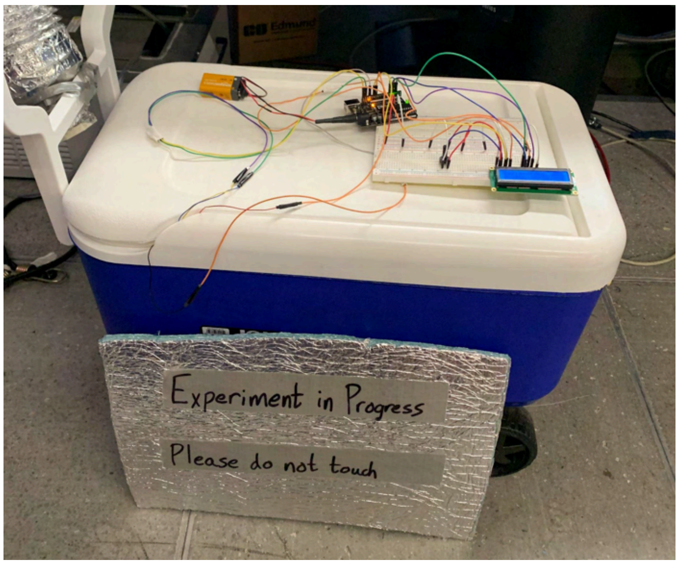


B.8. Wiring Diagram

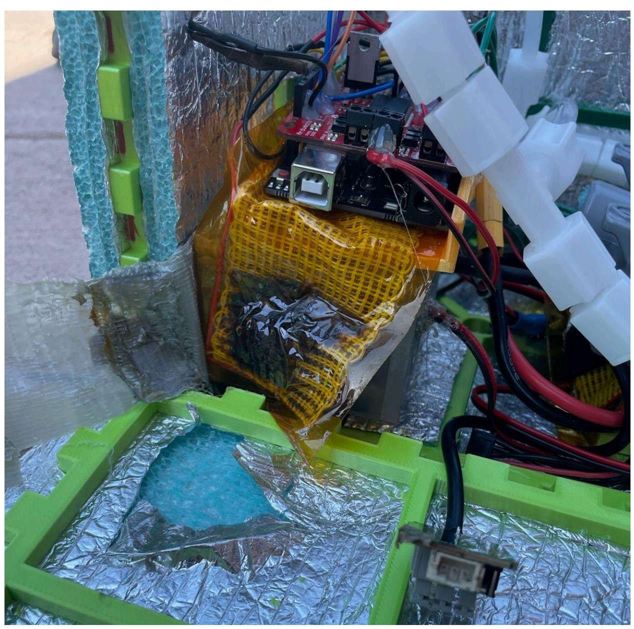


B.9. Functional Block Diagram

B.10. Second Iteration of Blood Reservoir



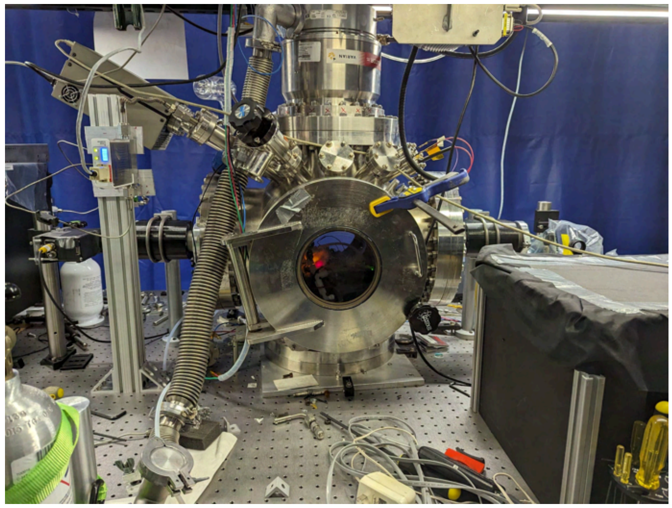
B.11. Cold Test with Dry Ice in a Cooler



B.12. Cold Test Failure

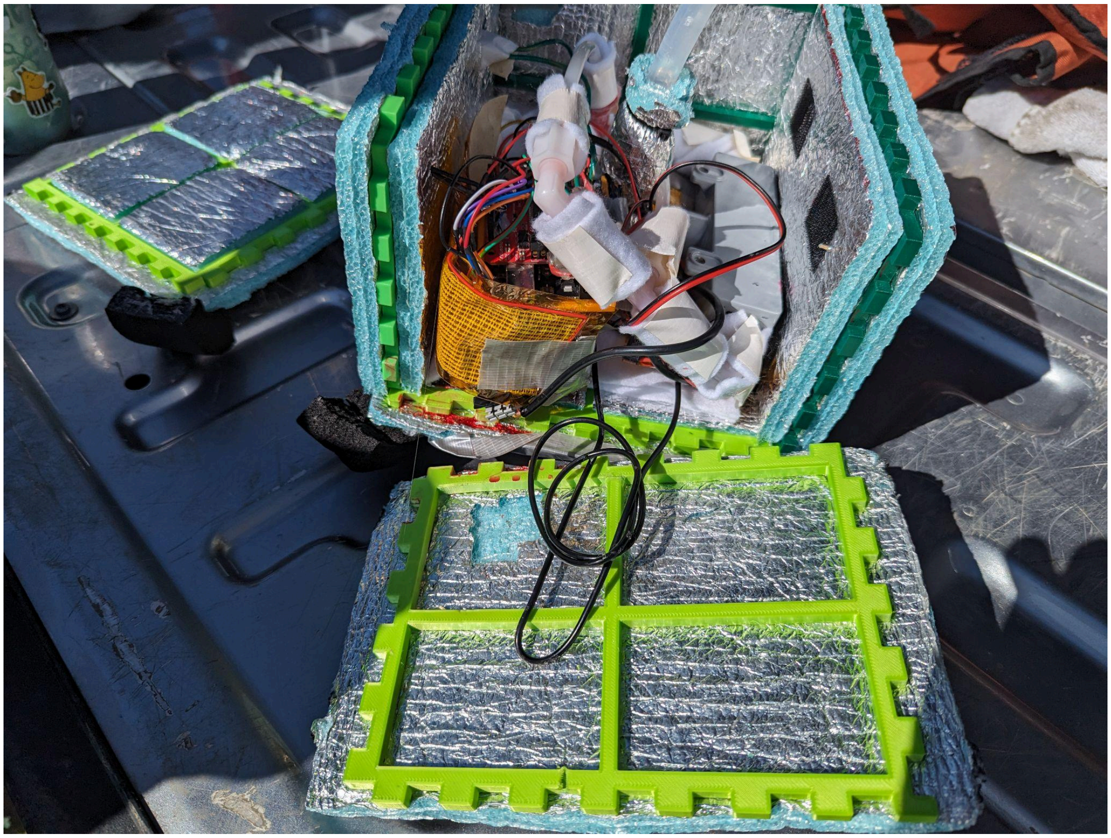
B.13. Drop Test

B.14. Whip Test



B.15. Payload Inside Vacuum Chamber

B.16. The Space Pigs and The Bacillus Boys Payload Recovery



B.17. Internals of Recovered Payload

SECTION 9: REFERENCES

[1] K. Mars, “Space Radiation is Risky Business for the Human Body,” *NASA*, Sep. 18, 2017. http://www.nasa.gov/feature/space-radiation-is-risky-business-for-the-human-body (accessed May 23, 2023).

[2] O. US EPA, “Cosmic Radiation,” Nov. 27, 2018. https://www.epa.gov/radtown/cosmic-radiation (accessed May 23, 2023).

[3] C. S. Agency, “How does radiation affect the human body in space?,” Canadian Space Agency, Aug. 18, 2006. https://www.asc-csa.gc.ca/eng/astronauts/space-medicine/radiation.asp (accessed Aug. 10, 2023).

[4] P. Ecker *et al.*, “Animal blood in translational research: How to adjust animal blood viscosity to the human standard,” *Physiol. Rep.*, vol. 9, no. 10, p. e14880, May 2021, doi: 10.14814/phy2.14880.

[5] R. Klabunde, “Viscosity of Blood,” *Cardiovascular Physiology Concepts*. https://cvphysiology.com/hemodynamics/h011 (accessed Aug. 08, 2023).

[6] S. Boës et al., "Control of the Fluid Viscosity in a Mock Circulation," in Artificial Organs, vol. 42, no. 1, pp. 68-77, 2018. DOI: 10.1111/aor.12948.

[7] Y. M. Chen et al., "Viscosity-Temperature Correlation for Glycerol-Water Solutions," Industrial & Engineering Chemistry Research, vol. 26, no. 8, pp. 1670-1672, 1987.

[8] R. E. Maples, Petroleum Refinery Process Economics, 2nd Edition. Pennwell Books, 2000. Accessed: Aug. 08, 2023. [Online]. Available: https://citizendium.org/wiki/Liquid_viscosity_blending