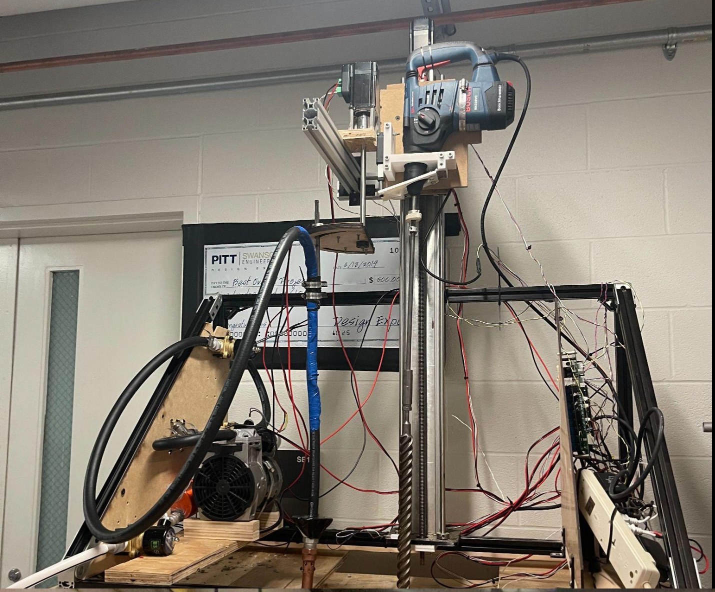
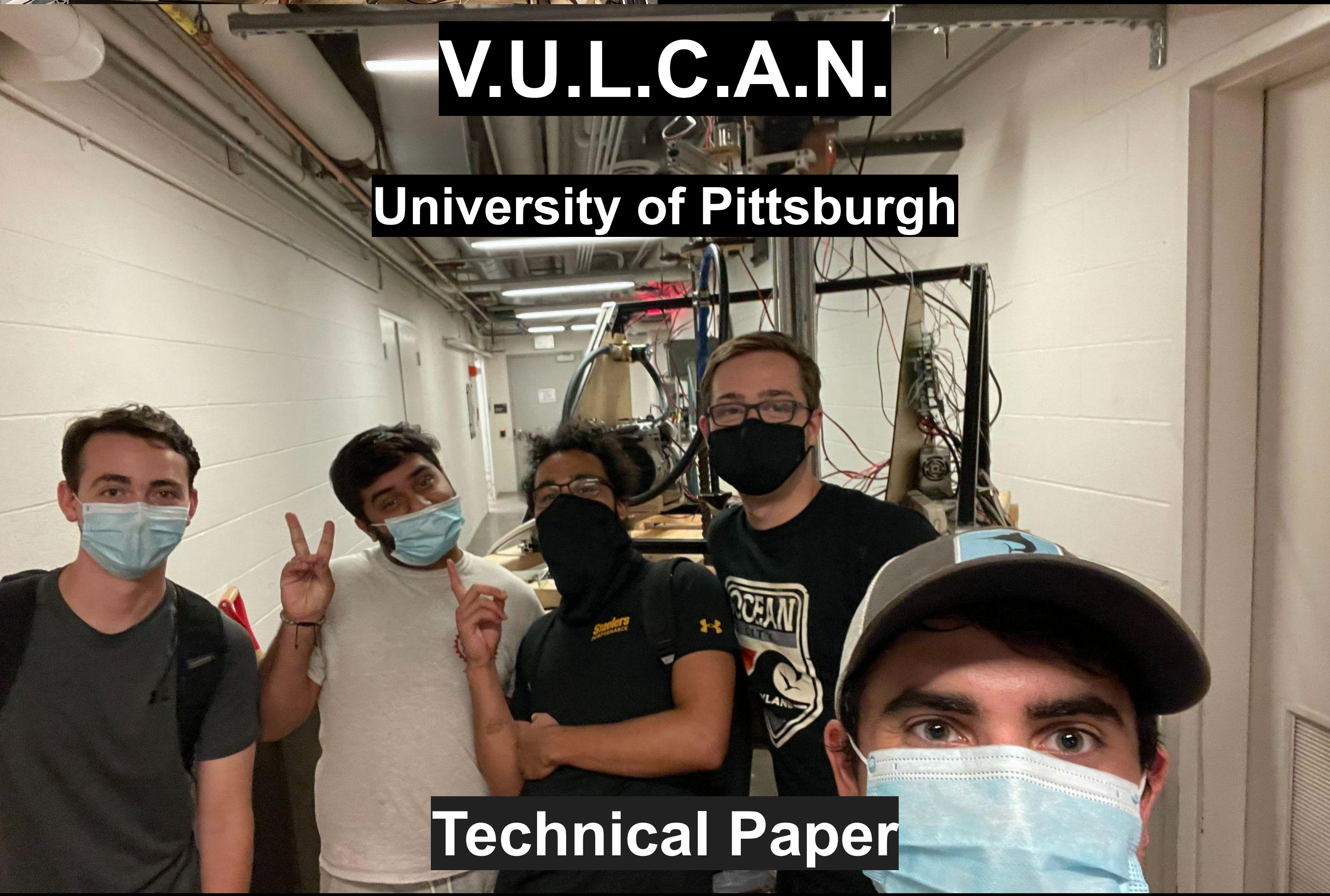


V.U.L.C.A.N.

University of Pittsburgh



Technical Paper

Members & Roles

Name	Role
Dr. Matthew Barry	Faculty Advisor
Fernando Tabares	Chief Engineer, Physics Undergraduate
Cole Bowman	Mechanical Lead, ME Undergraduate
Sushmit Acharya	Electronics Lead, EE Undergraduate
Andrew Horton	Digital Core Lead, ME Undergraduate
Ansh Baxi	Physics Undergraduate
Benjamin Moyer	ME Undergraduate
Caira Borchers	EE Undergraduate
Elizabeth Mountz	BioE Undergraduate
Jack Cornell	ME Undergraduate
Justin Olah	ME Undergraduate
Marissa DeFallo	ME Undergraduate
Patrick Bobko	Physics Undergraduate
Sam Hunn	ME Undergraduate
Zachary Colimon	CoE Undergraduate
Ronald Musto	ME Undergraduate
Elliot Kerachsky	ME Undergraduate
Ismael Mercier	Industry Advisor, Boeing

Executive Summary

VULCAN is designed to collect subsurface ice through a method of drilling, boiling, and vapor extraction. Mounted onto our frame is a vertical motion assembly utilizing a ballscrew translational system. We have a RH328VC Bosch Hammer Drill mounted to a plate on said vertical assembly. When operational, the vertical axis will descend the drill at 2 cm/min, and full power will be supplied to the drill, set to hammer + rotary action.

To examine the structure of overburden layers, an S-type load cell was integrated into the drill assembly. This is used to gather weight-on-bit data. Closed loop stepper motors allow accurate distance to be tracked. Weight-on-bit, current, and distance are recorded and plotted during operation; these are also exported to a .csv file for additional analysis.

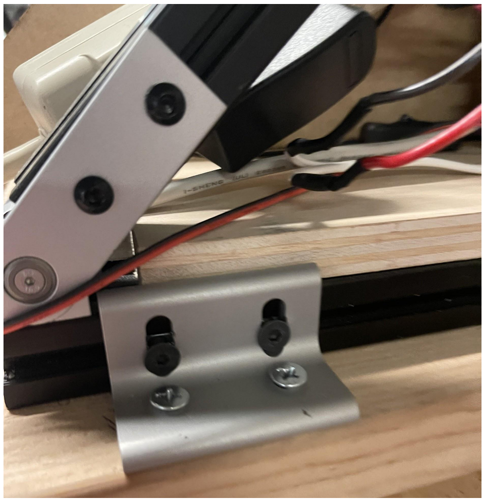
We wanted our system to be able to work on Mars with minimal changes. Thus, we decided to extract the ice as a vapor. The low atmospheric pressure on Mars will cause ice to sublimate when heat is applied. Thus, vapor was chosen to make our system on Earth as close to a hypothetical system on Mars as possible. Vapor will be absorbed through vents in the heat probe. The vapor will then run through a piston compressor, to drive the fluid and a condensation chamber to convert the vapor into a liquid where it then can be collected.

A passive filtration system was chosen to minimize power used and keep our system as lightweight as possible. By absorbing the ice in the form of a vapor, much of the debris in the ice can be ignored.

All code was written in C and flashed to an Arduino Mega 2560 in order to control all of the electronic components. A USB serial link between the Arduino Mega and a MATLAB-operated GUI allows for remote control and live sensory feedback from the electronic system. The Arduino toggles a SainSmart optocoupler 8-relay module to control the components powered directly from the 120V main supply: three valves, drill, pump, and heat probe. A 100kg S-type load cell with an HX711 amplifier relays live weight on bit data to the Arduino through I2C. The Arduino supplies the 5V needed to power the load cell and HX711 amplifier. One 24V NEMA 23 motor actuates the vertical assembly in the z-direction, and another powers the tool changer. The NEMA 23 motors have a built-in encoder with a resolution of 1000 pulses/second. This provides closed-loop control of the motor step size to ensure precise z-motion for the vertical assembly as well as reliable tool changer rotation. An L298n motor driver and 24V Transmotec linear actuator are used for tool changer functionality. A contactless ammeter allows us to monitor live current draw at the 120V main voltage supply, and a 9A fuse ensures that we do not exceed the competition amperage limitations. The drill can draw up to 8A, the heating element will draw 8.5A, and the pump will draw 1A. Only one of these high-current components will run at a time so as not to exceed the 9A limit. The 120V main supply powers all high voltage components through the relay switch and one 24V DC power supply powers the stepper motors and linear actuators. The 5V Arduino power supply provides logic voltage for the relays and motor controllers, as well as the power for the current and force sensor. All electrical components are powered with one power strip from the 120V main supply, one 24V DC power supply, and one 12V adapter.

System Description

Mounting



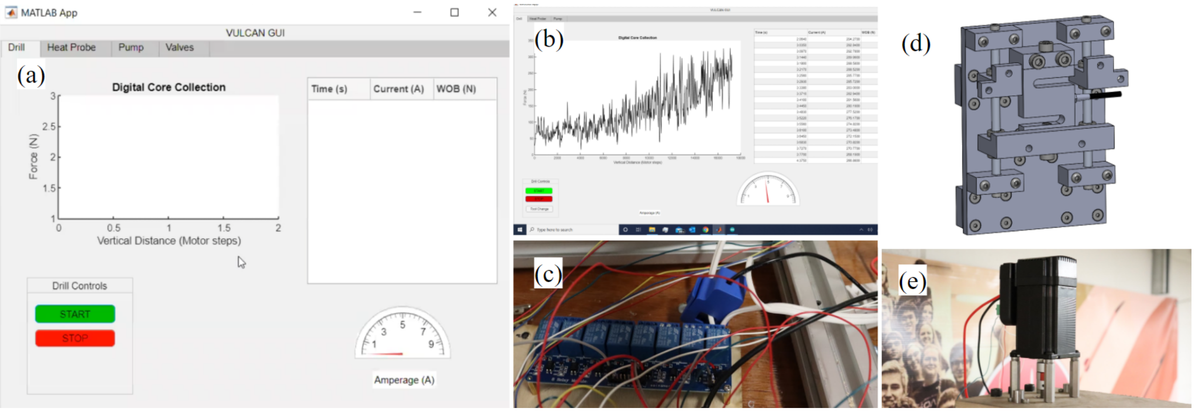
VULCAN will be attached to the mounting platform using 4 aluminum brackets fixed to the bottom exterior of our prototype with wood screws.

Drilling

To mine through the overburden layers, we will utilize a Bosch RH328VC Hammer. Our drill will be using full power with hammer + rotary action. When tested, this method has proven very effective at getting through the toughest overburden.

Digital core

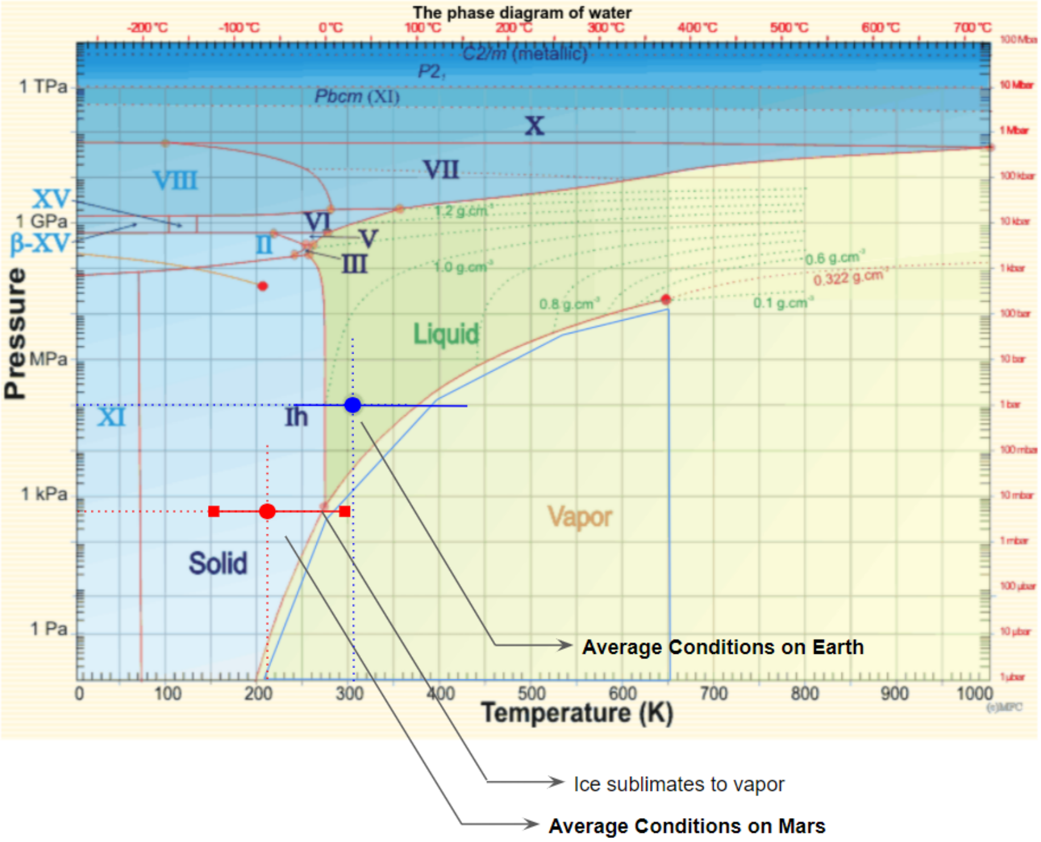
Measuring current and weight-on-bit are design requirements. This digital core design uses this telemetry in order to identify the correct soil layers. It's understood that harder layers will create more force on the drill bit; by plotting force versus distance, it is possible to see where layer transitions occur. Current logs are also revealing, as harder layers will require more torque from the vertical power screw, and therefore more current. Current, distance, and weight-on-bit readings are collected with the Nyquist-Shannon sampling theorem in consideration and relayed to the operator's computer with a constant serial data stream.



GUI (a), digital core data after a test run (b), current sensor (c), load cell placement (d), and encoder on stepper motor (e).

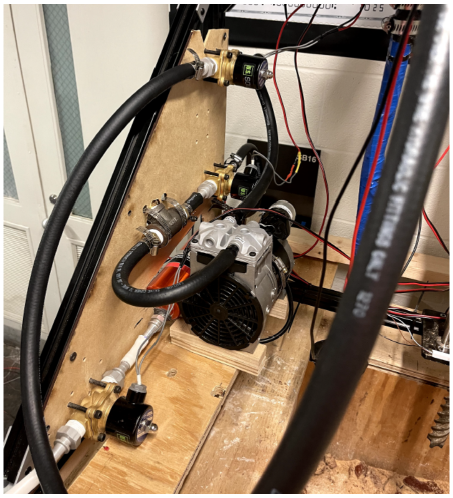
Water extraction system/technique

To extract the ice, VULCAN will boil the water underneath the regolith, and extract it as a vapor. Given Mars's atmospheric conditions, specifically the low pressure, it is possible to convert ice directly to vapor with the addition of heat. As our goal has been to develop a system meant for Mars, we have followed through with this approach. In a copper sleeve to disperse the heat, a 9A, 120V heating element will be activated to provide means for the phase change. Along with our heat probe used to extract the water, we use a sealing mechanism that employs a weighted cone to create a seal without the need for electrical power. The cone houses a linear bearing that slides along our heat probe tool. Once the hole is sealed and the vapor inside the drill hole has built up, we will cycle between running an air compressor as a pump and powering the heating element. This compressor feeds directly into our fluid system.

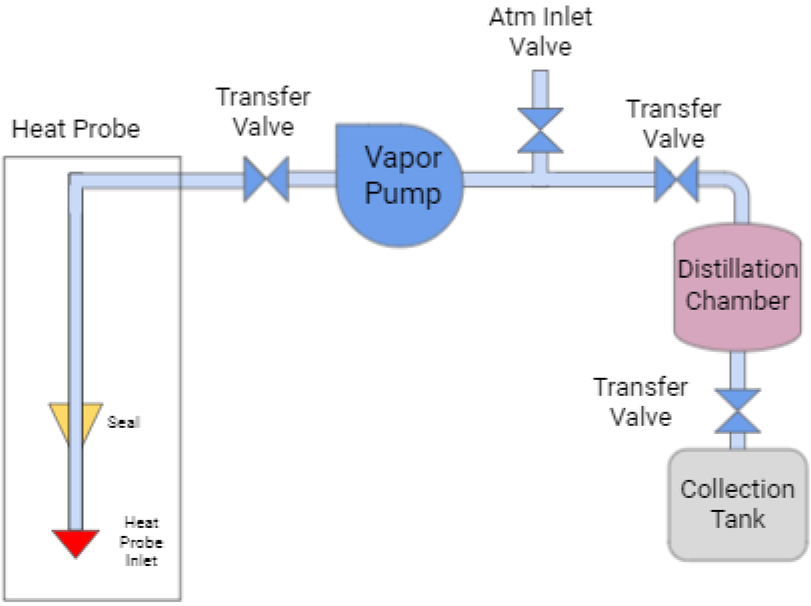


Phase diagram of water with range of operating conditions on Mars and Earth

Filtration and water collection



As the vapor is introduced to the system, a series of solenoids are opened to allow fluid flow. Once it passes through the compressor, the water is sent to a distillation chamber filled with steel wool to increase surface area for recondensing. After the chamber, gravity spurs the liquid water down to the collection tank. There is little need for a mechanical filtration system as only vapor will be extracted given the height of the opening from the ice. That said, a fine mesh is inside the probe vapor tube to reduce the chance of dust and dirt from entering the system.



A schematic of the thermo-fluids system layout.

Drill Freeze

Given the mechanical advantage of our vertical assembly, few measures were taken to prevent the drill from freezing to the ice layer. VULCAN should be able to unstick itself through a combination of the vertical axis motion, and pulsing of the drill extension.

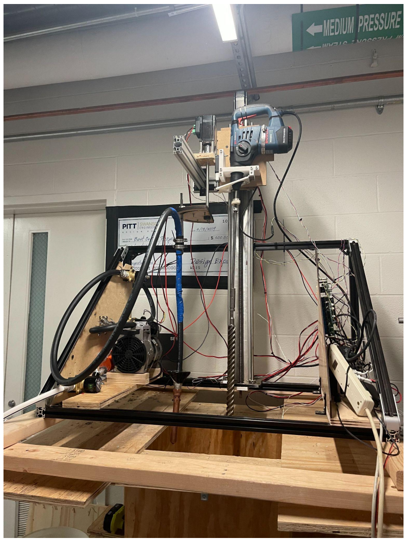
Control and communication system

All electronic components are controlled with a GUI-operated Arduino Mega 2560. The GUI is implemented in MATLAB, with four tabs: three main states and manual valve control. The three main states are for the drill, heat probe, and pump, and they ensure that only one high-current component is operating at a time. Each state has simple “Start” and “Stop” push buttons. The drill state has an additional option to interchange the drill bit and heat probe. The GUI controls the Arduino in real-time through serial connection, with code pre-flashed on the Arduino for each state set in the GUI. All electronic states are able to be operated easily and reliably with the GUI-operated Arduino.

Datalogger

We use a load cell to monitor weight on bit, and an embedded encoder in the NEMA 23 stepper motor to measure change in direction in the z-axis. All sensors are controlled with the Arduino Mega. Live sensory feedback is saved and displayed on the GUI. The weight on bit and z-motion of the drill for the digital core is displayed as a live digital core plot with an average of 91 milliseconds between data points. All data is saved and stored for later analysis. Live ammeter readout at the main power supply allows us to monitor current draw to prevent exceeding the maximum limit of 9A.

Technical Specifications



Overall mass: 42.82 kg
Overall volume: 1.2 m height, 0.82 length, 1.0 width
Drill type: BOSCH 1-1/8-Inch SDS-plus Rotary Hammer
Length of drill bit: 0.91 m
Weight on bit: Less than 150 N
Rated Load: 150 N
Max Drilling Speed: 900 RPM
Torque: 2.6 ft-lbs
Computer System: Arduino Mega 2560
Communications Interface: Matlab
Max Power: 9A, 120V ~1000W

Design Changes/Improvements

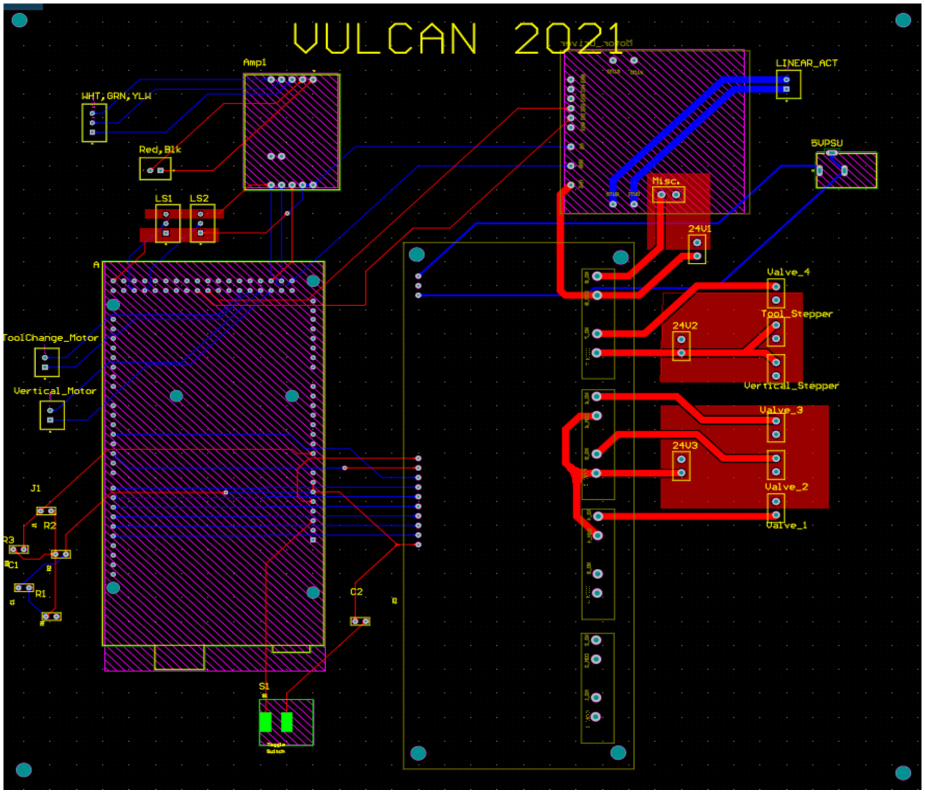
Since MPR, the team created a more stable platform for tool change operation. Before, there was a lot of undesired displacement of the tool change system (in the x-y plane) when a small force was applied. Our new attachment point reduces the deflection in the beam supporting the tool-changing plate. We also discovered that the tool changer motor does not have enough torque to perform as previously intended. Therefore a new function has been added to the control system to allow a pulsing of the drill to better align the bit for tool change to the heat probe.

We've also created a copper sleeve for our heating element used on the vapor extraction probe. This will allow for a more distributed concentration of heat that will melt the ice more thoroughly with a lower chance of burnout. The heat probe structure has changed as well. The heat probe's main body is now constructed from housing meant to withstand high temperatures and pressures. This hosing removes some of the extra components needed to build a continuous system.

Additionally, a PCB was constructed for multiple different reasons. First, in order to accommodate the interface between the ammeter and the Arduino a voltage divider was required. This circuit was first placed on a breadboard and free to error from any vibration. In order to successfully run a serial interface, we also required a capacitor to slow down the Arduino's reset process that would immediately power cycle the components connected to the relays. Initially 3 different 24V PSUs were used to power all the components, while only 2 components were powered simultaneously. Through the development of a PCB, the power distribution was constructed in branches allowing for one power supply to power multiple components. For these various reasons, the PCB proved to be critical in lowering mass, space and increasing the integrity of the controls.

Our method of system control has also evolved. While our software still had commands for various functions, the ability to remotely control individual movements in components has been streamlined for when unexpected situations/failures are encountered in operation.

While the foundations of a finite state machine remain constant for the software architecture, there are other certain changes that result in greater granularity of execution. For example, the tool change mechanism allows the user to control the rotation of the tool change plate along with the ability to manually extend and retract the linear actuator for tool release.



PCB Layout for the VULCAN system

Challenges

The Vulcan team has faced many challenges this past year, some due to Covid and others just from the growing pains of being a first-time competitor in the MMIP competition. One of the largest hurdles we had to overcome was not having access to a university owned machine shop. With Covid, the university was very reluctant to let us use their facilities to manufacture our prototype. Therefore, we had to spend some of our funding on getting access to a local public machine shop, and subsequently getting trained on the required machinery. This hampered us greatly in getting durable/final parts for our system, and set us back in our timeline. To make up for it, a small group of the team stayed for the month of May to work on the system after classes had ended.

Another hindrance in our expedition was that as a new club, there was a period of uncertainty as to who was going to end up being the core members of the team. As the year progressed, people found their desired roles and contributions to the team, and now we have a strong group of students firmly dedicated to next and this year's projects.

We also had significant difficulty in developing a reliable tool changer. A lot of the difficulty came from getting the drill bit to interface with the chuck after a tool change. The SDS+ interface that our drill has is only compatible in two orientations out of 360 degrees. In order to remedy this, next year we would like to eliminate the need for a tool-changer, perhaps using a carousel and/or two vertical translation systems - one for the drill bit, and one for the heat probe.

And lastly, our attempt to extract water vapor and recondense it into a clean liquid is a beast of its own. We wanted to implement some type of pumping component to increase the intake of vapor, but a water pump has a very low flow rate for vapor, if it's even able to run dry. And a compressor will not be able to handle the moisture for very long. We have been able to find a water-resistant compressor to use in this competition, but for future competitions the team would like to design a passive vapor extraction system.

Strategy for the Competition

- Extract as much water as possible
- Extract the cleanest water of all competition participants
- Ensure all components are working optimally
- Minimize excess electricity
- Minimize "hands on" time

Summary of Integration and Test Plan

Integration Test: On the day of the integration test, the respective leads complete final checks on systems, testing their systems and generally making sure everything is where it should be.

Mechanical Lead:

- Checks that tool changer lines up with the drill bit extension
- All screws on the tool changer and drill holding mechanism are connected
- Verifies that the Z axis lead lead screw assembly has solid connections and has fluid motion all the way through its extremes

Electrical Lead:

- Checks all wired connections on the PCB
- Makes sure no wires have gotten tangled in previous runs

Thermo-fluids Lead:

- Checks all of the tubing making sure it's properly secured
- Check that the compressor, solenoids, and condenser are securely attached
- Ensure capacitor on compressor is waterproof in order to prevent a short-circuit

Testing Lead:

- Sets up the testbed with the ice on the bottom and a mixture of materials including clay, red lava stone, river rock, and some concrete blocks in a random order and thickness
- Measures the heights of each level and writes them down to compare to the digital core
- Verifies the frame brackets are properly attached and sturdy

Once all leads have completed their final checks, the assembly is placed on the test bed and the ammeter is attached to the cord going into the wall outlet to verify the system does not go over the required amperage limits.

The next step is to lower the Z axis assembly so that the end of the drill bit is about a half inch from the surface of the overburden. The drill is then turned on and the Z axis is lowered at 2 cm/min. The drill is then run until it has made it to a depth of 1 in into the ice. We then cycle the drill in and out of the hole as the drill is running to make sure the hole is clean and the heat probe will fit. The drill is then returned to the top of the Z axis assembly, and the tool changing process begins.

During the tool changing process the chuck plate is raised by the actuator in order to release the SDS+ bit. Then the empty side of the tool changer is rotated around until the alignment disc is fully nestled into the slot in the tool changing carousel. At this point the drill is raised further to pull the bit extension fully out the drill chuck. The tool changing carousel is then rotated around in the other direction until the bit extension attached to the heat probe is positioned directly under the chuck plate. The chuck plate is then lowered to put the cone in the engaged position, which is then lowered onto the heat probe bit extension until an audible click is heard, meaning the chuck is fully engaged.

Once the tool changing process is complete, the heat probe is then lowered into the hole, and once the heat probe is hovering an inch above the ice surface, the heating cartridge is then turned on until it reaches its max temp and the copper sheathing is properly heated. The probe is then plunged onto the ice surface and steam is created as the ice melts. This also creates a pool of water in the ice block. Once the heat probe has cooled down to the point where it is not effective at creating steam, it is then turned off, raised off the surface of the water pool, and then the compressor is engaged, siphoning up the generated steam and running it through the condenser, which is then deposited in the output container as liquid water. The heating and condensing cycle is repeated until the ice in that hole has been used up, and we then retract the heat probe and start the drilling process over in a new location.

Results:

Our dry run developed into mixed results, with the drilling action showing great results, getting through a 0.25 meter mixed overburden in less than 5 minutes, and the hole that we created was clean and relatively free of debris. Some issues that came up were that our original plan to complete the tool changing was to code the switch from drill to heat probe as an autonomous process. This ended up not working as the weight of the heat probe increased the torque needed to turn the tool changing stepper motor, which made the motor skip steps, which messed up all of the timings and made it so a clean operation of the tool changing process was impossible. We have now decided to switch up the code architecture to one that allows slow, human controlled rotations and actuations to make sure that the tool changing process works every time. We were also unable to fully run the heat probe and compression system due to wiring issues caused by the immense power draw of the heating element. The gas compression system passed all of the checks we were able to give, freely allowing gases to be pulled in through the heat probe, and expelling those gases into the collection bucket. This test has been very beneficial as it has verified some of our systems, as well as showing us where we can improve, so we believe that we will be able to collect and deposit clean water at the end of our system.

Tactical Plan for Contingencies/Redundancies

In the event that;

The tool changer alignment mechanism fails to properly load a tool. The drill will Rotate for a brief period in an attempt to re-align the tool.

The drill becomes packed with “chips”. The drill will be retracted out of the hole while spinning similar to a full retract peck drilling cycle.

The heat probe fails to align with the hole. We will run a full retract and re-try lowering the heat probe into the hole.

A component structurally fails. A spare copy of all components with the highest risk of failure will be kept on-hand.

Additional Failure modes without contingency plans:

Water enters the lower section of the heat probe and short circuits the heater wires causing a short between the heater wires. At this moment, power to the system will be shut off.

The SDS plus shaft breaks of the heat probe tubing. This means we will no longer have control of the heat probe. We will leave the heater in the hole while turning the power off in order to allow the heat probe to cool down.

Safety Plan

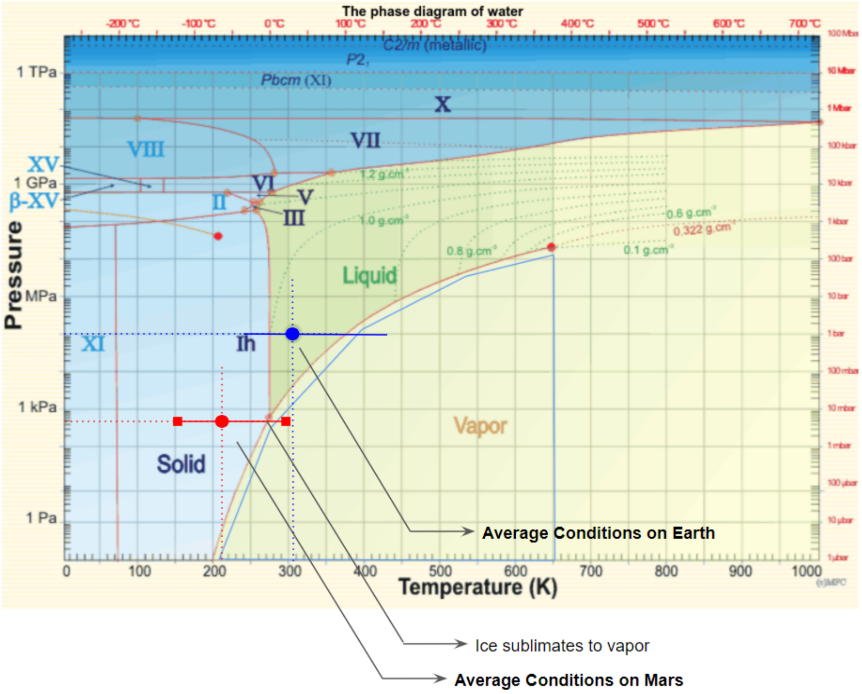
When doing any drilling operation safety glasses are required. This rule also applies to all stages of the ice extraction process. There are safety glasses available in our lab for team members to use when fabricating parts and while doing dry runs of the drill. In addition there are heat resistant gloves available for team members to wear when working with hot parts such as when testing the heat probe. These heat resistant gloves are to be worn exclusively for heat resistance. Using gloves of any kind while working with any kind of shop tool is dangerous and should be avoided. If gloves must be worn while working with machinery they must be thin surgical style gloves that will tear easily. This rule exists to prevent gloves getting caught in rotating spindles and pulling the wearer in. For this reason gloves are not to be worn during drill operation. For the same reason team members must remove any loose clothing and those with long hair must tie it back before working on the drill in any way. This also applies when running the drill. Our drill design uses no hazardous materials once constructed.

Paths to Flight

To Mars

When the Pitt’s Mars Ice Team decided to compete for the first time this year, we were most excited to develop a system that could potentially be used on Mars one day. That being our main motivation for competing, we opted to make a system intended to operate on the red planet, not Earth. Then we would retrofit our design to work more effectively on Earth. This was our general approach throughout the year, and had a large impact on our extraction method.

The primary differences in the operating environment that will affect the system’s basic effectiveness are temperature and pressure. More specifically we have to look at how they affect the properties of water. With standard Earth conditions, when heat is applied, water shifts phases from ice to water to vapor. Whereas on Mars, given the average atmospheric pressure and temperature, ice passes the triple point on the P-T diagram as temperature is increased, sublimating in the process.



P-T Diagram with Temperature Ranges for Earth and Mars

To go more into the Martian conditions that would be affecting us;

Average temperature on Mars is -60 degrees Celsius (-80F, 210K), while extreme Temperatures range from -125C (148.15K) to 20C (293.15K) depending on location on Mars. Conditions are also subject to major fluctuations due to the thin atmosphere (low thermal inertia). Fluctuations of over 100 C within 6 hours can occur. Some materials have different shear strengths as the temperature changes. So having many of these fluctuations can create fractures in the structure that grow until failure. Therefore there will need to be a way to regulate the temperature in the system or design with expansion fatigue and fracture stresses in mind. One solution may be to use a nuclear-based power source to regulate the system's temperature.

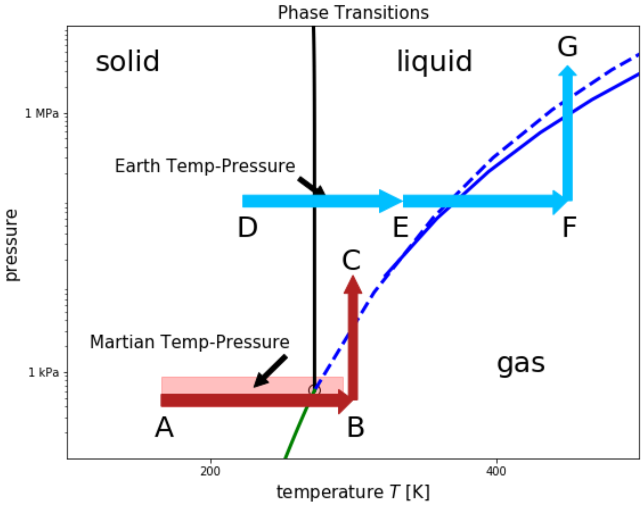
Mean surface pressure is 610 Pascals (0.088psi, 0.006 atm), and ranges from 100 Pa to 1500 Pa.

Drill would need to be made of materials that have low levels of outgassing

Outgassing is when air molecules stuck in plastics are released to the atmosphere. This gas trapped in plastics/other materials can condense on camera lenses, making them inoperable

As shown on the previous page, the range of natural temperatures and pressures on Mars only allow H_2O to be in either solid or gaseous form, since this range lies below the Triple Point. This means that if heat is added to ice in order to trigger a state change, the ice will convert to gas. Simply, liquid water is not stable on Mars. The single combination of pressure and temperature at which liquid water, solid ice, and water vapor can coexist in a stable equilibrium (i.e. the Triple Point of Water) occurs at approximately 273.1575 K (0.0075 °C; 32.0135 °F) and a partial vapor pressure of 611.657 pascals (6.11657 mbar; 0.00603659 atm). At that point, it is possible to change all of the substance to ice, water, or vapor by making arbitrarily small changes in pressure and temperature.

All of this information leads us to believe if we are to make a system to work on Mars, we should focus on extracting the ice as a vapor, not as a liquid. This does somewhat hamstring us for competing on Earth. We will have to use much more energy to achieve the desired state. However, we have found a heating element for our probe that is within the power constraints that can boil water while encased in it's own bowl of ice. The vapor extraction process will function more efficiently on Mars, needing less power to get the ice into a harvestable form.



The graph above shows the difference in energy between Earth and Mars needed to complete the phase changes our system requires.

The reason that water vaporizes more easily on mars is due to the reduced pressure (0.87 - 0.4 Kpa) of the atmosphere. The temperature on Mars (166K - 293K) is almost always below that of the triple point of water(273.16K). Due to this the water we find can be converted to gas simply by heating it beyond the triple point.

The nature of the martian atmosphere means that ice when heated will turn into gas. Our system takes advantage of this fact in order to extract clean water easily by distilling it. This leaves most residue from the ice behind in the dirt and extracts clean water during the condensing step. This advantage helps reduce flight weight by eliminating consumable parts required in a filtration system.

Extracting ice in the gaseous form presents it's own challenges. The first and most obvious challenge is containing the gas. As discussed previously the sides of the drilled hole in the regolith are almost certainly porous. The porosity of the hole is not a problem addressed fully by the VULCAN system however in the brainstorming process a proposed solution was to simply limit the exposed regolith in the drilled hole by sealing the entrance to the drilled hole. This limits the rate at which gaseous water will escape extraction via the VULCAN system.

Other Changes

To summarize, our water extraction method can remain relatively unchanged in it's process. We would however need to develop a way to clear the pipework of possible debris, and our solution to use a compressor to increase steam input will need to change in order to improve lifetime. Next year we would like to attempt a passive steam collection system.

Dust and radiation shielding will also be required to withstand the harmful effects of the Martian atmosphere. The dust on Mars will get into the mechanical components of our system and cause failures. It erodes the structural integrity of our hardware While the electronics are at risk of damage due to the radiation, given Mar's light atmosphere.

Our team had significant difficulties in getting access to manufacturing equipment, some of our components are constructed out of wood and MDF board. These pieces will need to be made out of aluminum for durability and weight-saving purposes. More improvements should be made to our vertical axis assembly. The rails the drill travels along are flexible, and create unneeded instability when our drill is in motion. The drill securement method also needs to be reinforced and more rigid.

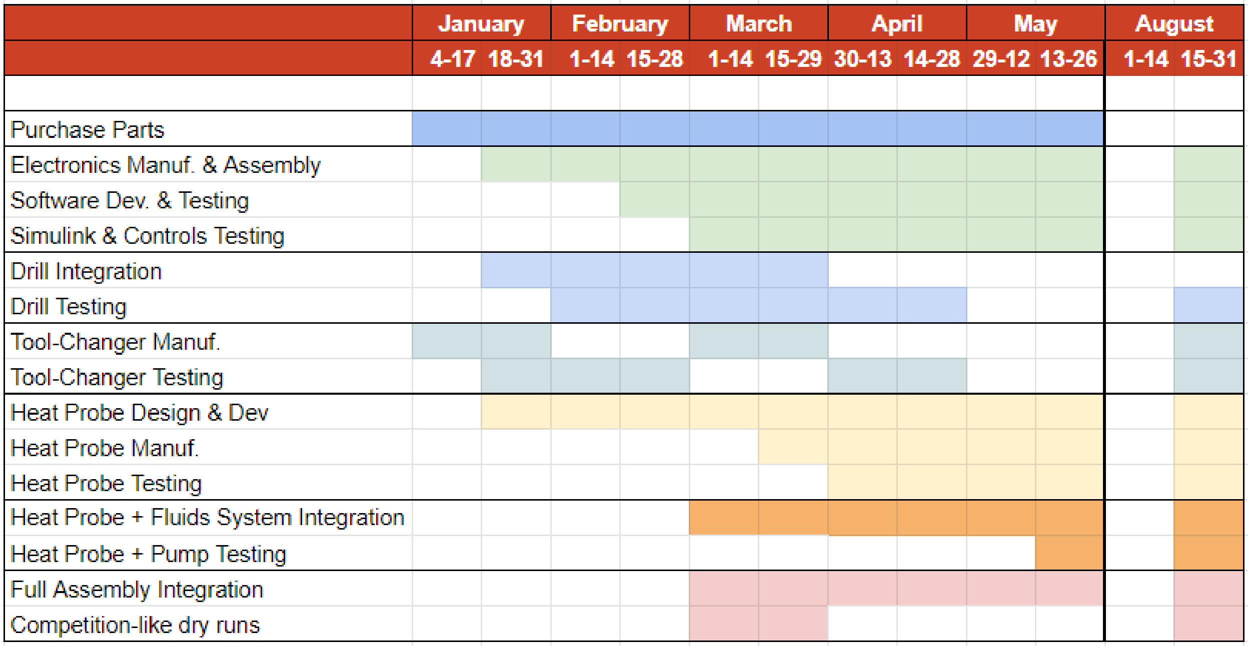
Given that our system is oriented to receive power from a standard wall outlet, a new power supply system would need to be created for Mars and Moon functionality. Using a nuclear-based power source would be preferred, as mentioned earlier excess heat can be used to keep the water in a stable liquid form once collected. And since our system is immobile, and we currently have no astronauts on Mars, VULCAN will have to be remotely moved from place to place to continue collecting water. Ideally, the system can be placed on a rover, and use its method of travel to find new ice pockets to extract.

To the Moon

The differences between the Earth and the Moon from an excavation standpoint are significant. The Lunar atmosphere has an almost nonexistent pressure, around 3 x 10^{-10} Pa, which makes water exist in either a solid or gaseous state according to the phase diagram of water. The temperature on the Lunar surface also presents a new and different challenge, as it varies from -183 ℃ to 106 ℃, which is much higher than the temperature variance on either Earth or Mars. For the purposes of prospecting, the pressure and temperature conditions on the surface provide a similar challenge to the conditions on Mars, but our system is uniquely built for exactly this problem. With the use of gaseous extraction, we can perform our excavation process in mostly the same manner as we have planned for Mars, taking advantage of the fact that the water will sublimate before it turns to a liquid at that pressure. In terms of the overall VULCAN drilling process, we would not have to make any significant changes to the system for it to be functional and effective on the Moon.

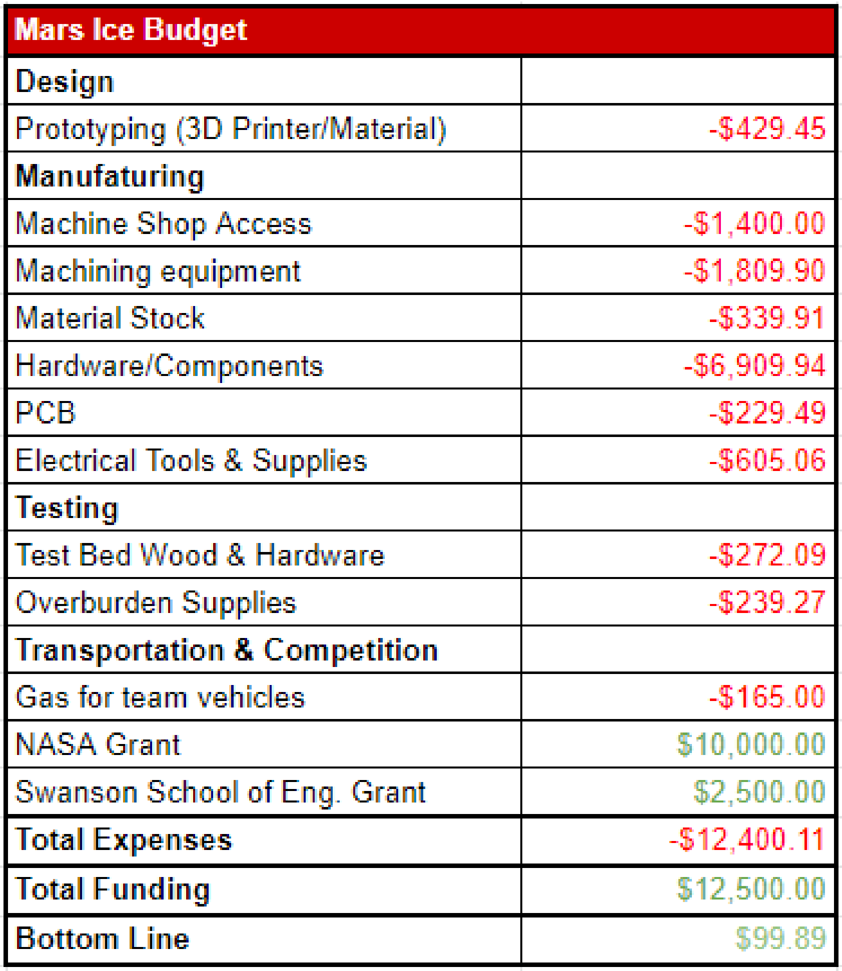
However, the Moon does provide some smaller obstacles to system functionality. The Moon's weaker gravitational pull would mean that the manual tool changing process would have to be adjusted to make sure neither the drill bit nor the heat probe go in a direction the operator did not intend. To mitigate this, we would slow down the operational speeds of both stepper motors to make sure that the operator can move and change parts without imparting any significant forces on the components. We would also attach a spring loaded gate to the openings on either side of the tool changer plate that would eliminate the possibility of either component exiting the tool changer under their own force. Some other considerations we would need to account for is debris, as the the rock we expel from the hole will not be stuck to the ground like on Earth, so we would have to build in extra protective shielding for cables, electronics, and any fragile machinery within view of the prospecting hole to mitigate the danger of debris interfering with the mechanical and electrical operations of the system. We would also need to provide significant temperature and radiation shielding to all of the electronics to make sure that they are not damaged by the harsh UV rays that can be very destructive in a non-atmospheric environment.

Project Timeline



	January		February		March		April		May		August	
	4-17	18-31	1-14	15-28	1-14	15-29	30-13	14-28	29-12	13-26	1-14	15-31
Purchase Parts	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦		
Electronics Manuf. & Assembly		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		🟩
Software Dev. & Testing				🟩	🟩	🟩	🟩	🟩	🟩	🟩		🟩
Simulink & Controls Testing					🟩	🟩	🟩	🟩	🟩	🟩		🟩
Drill Integration		🟦	🟦	🟦	🟦	🟦						
Drill Testing			🟦	🟦	🟦	🟦	🟦	🟦				🟦
Tool-Changer Manuf.	▨	▨			▨	▨						▨
Tool-Changer Testing		▨	▨	▨			▨	▨				▨
Heat Probe Design & Dev		🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨		🟨
Heat Probe Manuf.						🟨	🟨	🟨	🟨	🟨		🟨
Heat Probe Testing							🟨	🟨	🟨	🟨		🟨
Heat Probe + Fluids System Integration					🟧	🟧	🟧	🟧	🟧	🟧		🟧
Heat Probe + Pump Testing										🟧		🟧
Full Assembly Integration					🟥	🟥	🟥	🟥	🟥	🟥		🟥
Competition-like dry runs					🟥	🟥						🟥

Budget



Mars Ice Budget	
Design	
Prototyping (3D Printer/Material)	-$429.45
Manufaturing	
Machine Shop Access	-$1,400.00
Machining equipment	-$1,809.90
Material Stock	-$339.91
Hardware/Components	-$6,909.94
PCB	-$229.49
Electrical Tools & Supplies	-$605.06
Testing	
Test Bed Wood & Hardware	-$272.09
Overburden Supplies	-$239.27
Transportation & Competition	
Gas for team vehicles	-$165.00
NASA Grant	$10,000.00
Swanson School of Eng. Grant	$2,500.00
Total Expenses	-$12,400.11
Total Funding	$12,500.00
Bottom Line	$99.89

The MMIP registration fees will be covered by next year's university grant, and hotel expenses are expected to be covered by Student Government Body