Capstone Design Program
College of Engineering and Computational Sciences

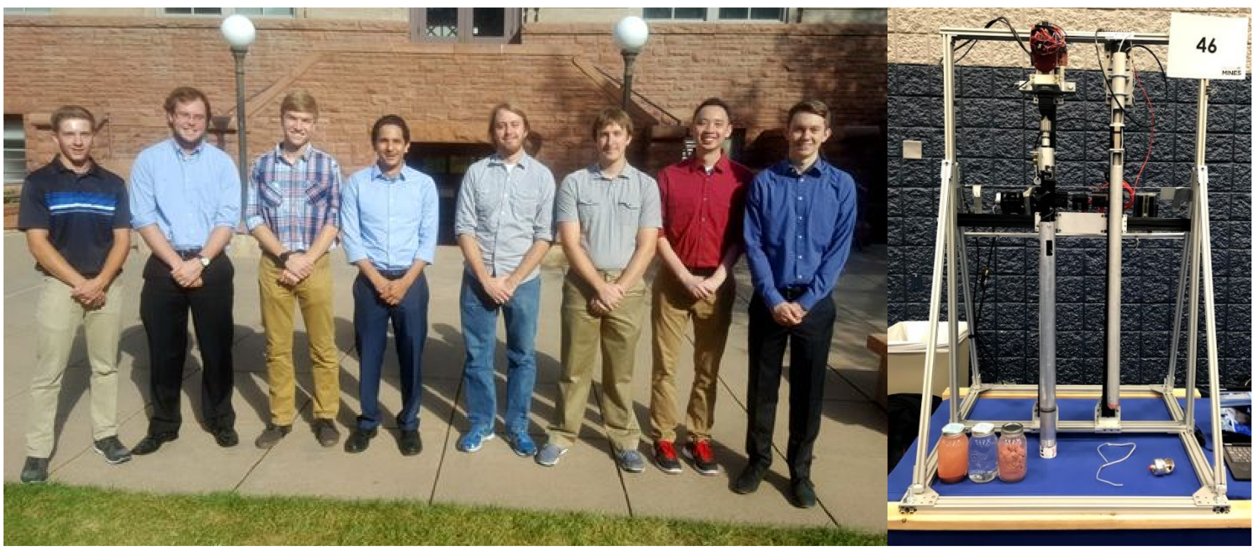
COLORADO SCHOOL OF MINES
GOLDEN, COLORADO 80401-1887

2018 RASC-AL Special Edition: Mars Ice Challenge

Team MINERS

(**M**artian **I**ce **N**ew-Age **E**xtraction & **R**ecovery **S**ystem)

Technical Report



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Introduction

The 2018 RASC-AL Mars Ice Challenge has given university teams the task of developing a prototype drilling rig capable of extracting simulated Martian subsurface ice. Team MINERS from the Colorado School of Mines has designed and created an innovative drilling system capable of removing large amounts of clean water for use by Martian astronauts. The drill consists of two major subsystems: an auger and a heat probe. The auger creates a hole in the regolith and drops a casing to maintain the hole stability. The heat probe is then dropped into the hole where it begins melting the ice and pumping out the resulting water. Our team hopes to drill and melt simultaneously to increase efficiency in extracting water. Included in this report are subsystem descriptions, technical specifications, design changes, challenges faced, competition strategy, and the path-to-flight plan for use on an actual Mars mission.

System Description

Team Miners has chosen a system that utilizes two main extraction sub-systems. The first system consists of an auger and casing which removes a cylindrical column of regolith in order to expose the ice. The casing is then detached from the drill and left in place so that unconsolidated material does not fall back onto the ice. A heat probe is then inserted into the casing/borehole and penetrates the ice via melting. The following sections detail each subsystem dedicated to driving this two-step extraction process.

Mounting System:

The chassis for the drilling rig is constructed out of 6105-T5 T-slotted aluminum extrusions. The base of the chassis consists of a 0.95m square platform of 25x50mm extrusions that will rest on top of the competition test station. Two sides of the chassis base will rest upon the provided wooden 2x4's while the other two sides span between the boards to support the main load of the drilling system. Each of the 4 corners of the chassis base are bolted onto the 2x4's using ½" hex bolts and washers. The bolts are inserted from the bottom of the 2x4's, and counterbores are drilled in the bottom holes so that the heads of the bolts lie flush with base of the boards.

System Excavation Operations:

Our system uses a 2 inch diameter earth auger to excavate the clay overburden. The auger connects to a Hilti rotary hammer drill. Our team chose to use an auger system as it is a widely used extraction method. Also, the team that Mines sent last year used an auger system to run both excavation and ice extraction so our new team was able to see where that team went wrong and what we needed to do to fix the problems. Connected to the auger is a borehole casing with a 2 inch inner diameter to fit snugly around the flutes of the auger. The casing is comprised of two separable parts. The top part of the casing is connected directly to the top of the auger using a ⅜" bolt. The top part of the casing connects to the bottom part using a spin locking mechanism. This locking system entails 3 slotted brackets on the top part of the casing which lock onto 3 round nuts on the bottom part of the casing. When the drill is spun forward, the casing locks and spins with the auger. On the bottom of the casing is a hole saw, which aids in cutting through the clay. As the auger spins and descends into the regolith layer, the casing spins and descends along with it. The casing helps loose dirt ascend the flutes of the auger by keeping the dirt from falling off the sides of the flutes. The loose dirt exits via slots machined in the above-surface portion of the casing. The auger/casing assembly drills down through the regolith layer until the ice layer is reached. The casing and auger drill approximately one inch down into the ice layer, and the drill is run stationary until as much dirt has been excavated from the hole as possible. This confirms that the hole is as clean as possible for the subsequent heat probe operation. Once the hole has been drilled deep and clean enough, the drill is run backwards briefly, causing the casing spin lock to detach. The auger is then lifted out of the hole while the newly detached casing is left in the hole to provide structural integrity to the hole and prevent new dirt from entering. Once the auger has been lifted out of the casing, the heat probe is actuated over hole and descends through the casing to reach the exposed ice. Figure 1 below shows a visual rendering of the described drilling system.

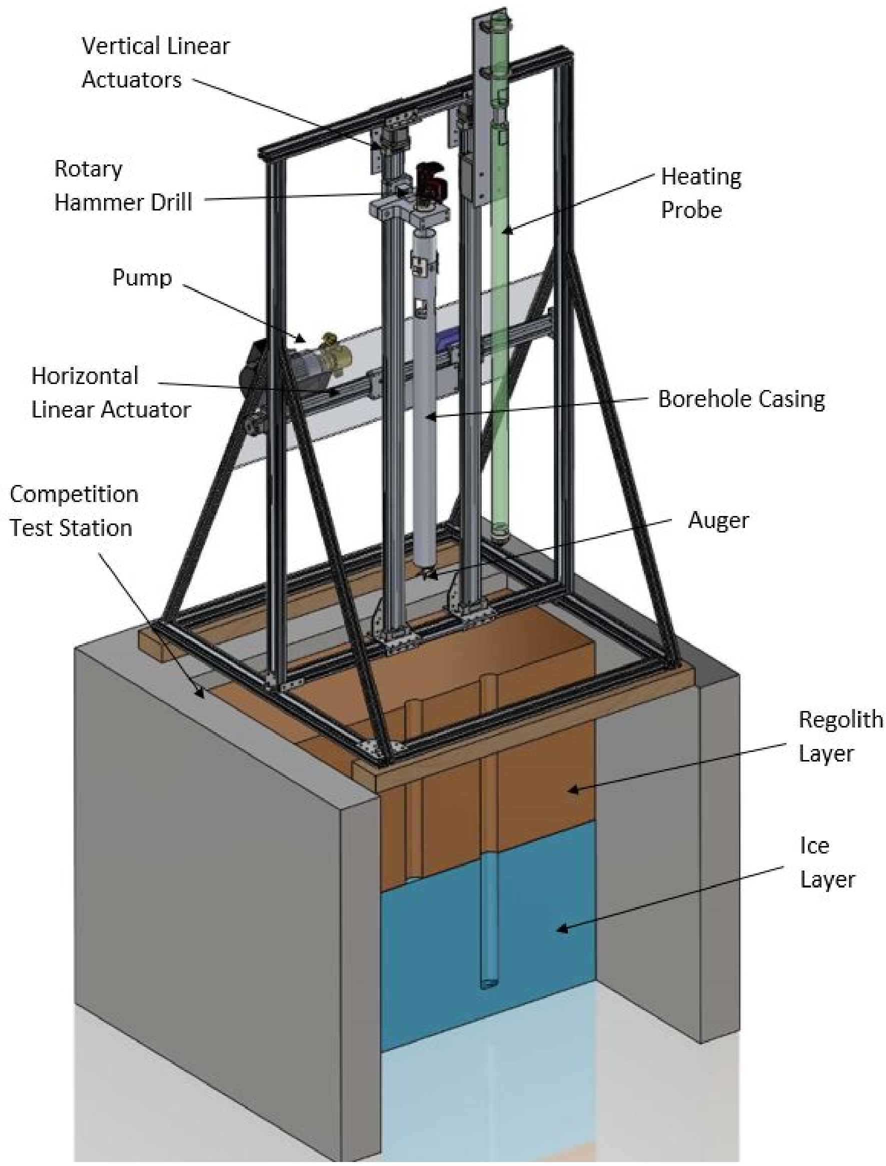


Figure 1: Rendering of Earth-based drilling system

Water Extraction System/Technique:

Water extraction for our design is handled by a heating probe. It is comprised of an aluminum case which houses all wiring and a vacuum tube, a copper heating tip which is the primary element melting the ice, and a metal connection piece that is the link between the tip and case. The copper tip houses a heating rope much like you would find wrapped around pipes to keep them from freezing. With the use of this rope which has an operating temperature of 900°F, our copper tip conducts a large amount of heat into a controlled area which helps the team precisely melt water. A vacuum tube that runs through the center of the assembly, which is connected to a pump, handles all of the extraction of the newly melted water.

Filtration and Water Collection:

Due to the drilling environment in which the pump will be operating during the competition, we devised a number of criteria to ensure that our pump would function properly during competition. The pump must be able to run dry as there will be times where the water supply will be intermittent. The pump must be self priming. During the second half of the competition, we are not allowed to touch our system and thus we could not prime the pump. Finally, the pump must have a head of at least 3 meters. This is the maximum height of our drilling rig plus the total depth of the test system and thus we must plan for the pump to lift the water at least that high. After considerable research, the pump our team chose for our final design was the Shur-flo Park Pump Model 4008-171-E65. It is rated at 55 psi and 3 gallons per minute. It can run dry, is self-priming, and runs at 115 VAC and 1 amp max.

The piping is ¼" plastic push-to-connect tubing. This allows the pumping system to easily be disassembled and reassembled at multiple locations if a clogging issue arises during the first half of the competition. The ¼" tubing size provides a balance between allowing large amounts of water to flow and increasing the pressure within the pipe to lift water multiple meters of height. The total piping length is around 9 meters. This allows 3 meters of pipe to thread over the top bar of our frame and down through the center of the heat probe to the heat probe tip. Here is it connected using a push-to-connect NPT adapter that threads to the back of the aluminum heat probe tip connector. This adapter creates further separation from the hot heat probe tip and minimizes the risk of melting the plastic tube. Another 3 meters of tubing runs from the top of the structural frame, through the pump and down to the floor supporting the test system. The final 3 meters runs from the testing system to the bucket provided by NASA to collect water.

After numerous iterations of filter design and orientation, our team decided on a three-stage filtration system to ensure the water is as clean as possible and to increase the amount of sediment our system can hold before clogging. The first filter encountered is a round coarse mesh that is attached over the hole at the tip of the heat probe. This is a very first defense that prevents large particles and large amounts of sediment from entering the system. It is specifically meant to keep particles that are close to ¼" from being sucked up and getting stuck in the pipes. The openings on the mesh are 0.034". The second filter is a coarse mesh capture device located directly upstream from the pump. This filter is finer than the wire mesh at the tip and prevents smaller particles from entering and potentially damaging the pump. The catch in this filter allows it to collect quite a bit of sediment before clogging. The catch can be unscrewed and cleaned out very easily. This may be a procedure we consider in the time between the two days of competition and it allows flexibility within our filtration system.. The third and final filter is a commercially available filter manufactured by Sawyer Products. It is custom mounted to our system. The filter is called a "Squeeze Water Filtration System". The filter is extremely fine with a 0.1 micron mesh. removing any sediment remaining in the water and leaving water that looks extremely clear. It is also a purifier and removes nearly all bacteria and protozoa from the water. The filter can be detached and backwashed using a syringe in the case of the filter clogging.

Solution to deal with the overburden:

Our team has chosen to use the aforementioned casing that will protect our system from the overburden. During overburden extraction the auger is connected to the casing which has slots at the top to allow overburden to travel up through the casing and out the holes falling back onto the surface of the sample site, but keeping it outside of the new hole being drilled. Once drilling has completed, the auger can detach from the casing and then be removed, leaving only the casing to stay behind in the hole and keep the walls of the hole from collapsing during water extraction. This casing is critical to keeping our drilled hole clean for heating probe operations.

Process for managing temperature changes to prevent drill from freezing in the ice:

During auger drilling operations, both the auger and casing only drill slightly into the lower ice layer. Due to this and the expected heat created from rotational friction between the casing and ice, the casing is not expected to experience refreezing during drilling operations. To ascertain that the casing does not experience significant refreezing, the casing will not be drilled more than 1 inch into the ice layer. For heating probe operations, we will be relying on conduction heat transfer to prevent the ice from refreezing onto the heat probe. The copper heat tip will be consistently hot during operations due to its internal heat rope and high thermal conductivity. The aluminum case for the heat probe will maintain a cooler temperature than the tip since it does not have heating rope in direct contact. However, the team believes that enough heat will conduct up the probe case walls from the heated tip to prevent significant refreezing on the heat probe case exterior walls. In addition, the pump will be constantly extracting all available water so that the walls of the ice borehole contain little moisture that could refreeze onto the exterior of the heat probe case. This will limit the amount of ice that freezes on the heat probe and therefore limit the force required to break the heat probe free.

Control and Communication System:

The control interface system uses LabView and a myRIO 1900 from National Instruments. There are three stepper motors under the system's control. There is one that translates the drill and heat probe horizontally and there is one that translates both the drill and heat probe vertically. The three motors are all controlled by a pulse width modulation (PWM) output to control frequency and duty cycle during the operation and a digital out signal to control the direction of the rotation.

In addition to the stepper motors, the drill motor is controlled by a light-sensitive photoresistor. The motor is a Hilti TE 7 rotary hammer that was hacked to enable speed and direction control through LabView. The myRIO sends a PWM signal that controls the brightness of an LED. The LED is mounted directly in front of the photoresistor and electrical taped together to ensure that all the light goes directly to the photoresistor. This control system for the drill is mounted in a 3-D printed enclosed container.

A rectangular load cell was placed between the vertical actuator and the drill motor to provide the WOB of the drilling system. There is also an S-shaped load cell that is placed in the heat probe system to measure the WOB of the heating system. Each load cell requires an amplifier to boost the output signal. The data is collected from the sensors and recorded through an analog input voltage from the amplifiers. The voltage collected from the sensors will be then converted to WOB. There is a heating rope that is coiled inside the heat probe tip and will be powered by a digital output signal from the myRIO. The pump is also controlled by a digital output signal from the myRIO.

The main electrical system is mounted onto an aluminum panel that is located behind the drilling system. They are placed behind the drilling system to prevent the debris from the regolith from coming into contact with the electrical components. The panel allows easy access to all the electrical components as well as the power supply.

Datalogger:

The myRIO will collect voltage readings from the load cell amplifiers and these voltages will be converted into WOB. The WOB data will be plotted on a graph on the interface to provided real-time tracking of the WOB during the operation. There will be two sets of data for both the WOB on the drill actuation and the heat probe actuation. As for the current usage, there is a non-invasive current sensor placed near the electrical panel that will provide real-time data of the electrical current usage. This value will be shown via a display box on the interface. The temperature of the heat probe tip is monitored using a thermocouple and displayed in celsius.

Technical Specifications:

Table 1 below outlines some of the specifications for the prototype drilling rig used at the competition for Earth-based testing.

Table 1: Technical specifications for Earth-based prototype

Mass (kg)	Volume (m^3)	Length of Drill Bit (m)	Max Operating WOB (N)		Chassis Rated Load (N)	Max Drilling Speed (rpm)	Torque (N*cm)			On-board computer system	Communications Interface	Software	Max Power Draw (W)
			Auger	Heat Probe			Drill	Horizontal Stepper Motor	Vertical Stepper Motors				
56.7	1.64	0.965	95	80	2200	1050	5500	35	90	Windows 10	NI MyRIO	LabVIEW	936

Design Changes/Improvements

Since the mid-project review, the team has made several design changes to better extract ice from the competition test station. During initial testing, the team was using the drill from last year's Mines team. However, with the custom wiring modifications done by the previous team, the drill did not have enough torque to effectively spin the auger through large amounts of dirt. Because of this, the team chose to invest in a new Hilti TE 7 rotary hammer drill to provide better power to the auger for drilling operations. In addition to providing more torque and speed to the auger, the rotary hammer provides us with the option to use percussive drilling to more effectively drill through the regolith layer. To gain control over the drill, the drill was taken apart and rewired with a modified speed control circuit to control the rotational speed of the drill along with the drill direction.

Another necessary modification was choosing a new auger. Initial testing with the auger from last year's team showed that the auger tip was ineffective at removing dirt from the base of the drilled hole. Therefore, the team bought a new earth auger with a tip that more effectively brings dirt up to the flutes of the auger when drilling. This new addition will help to decrease the drill time and required weight-on-bit to drill at the same penetration rate.

Initially, the team was using a 2 inch diameter heat probe prototype for preliminary testing. This meant that the heat probe fit into the casing without much room on the sides. If we were to use this diameter heat probe at competition, we would have to perfectly line up the heat probe to drop it into the casing to melt the ice. Due to uncertainties in lining up the heat probe concentrically with the casing, we chose to decrease the diameter of the heat probe to 1.75” to give us some tolerance between the heat probe and the casing. That way, if our heat probe or borehole were not perfectly vertical, the heat probe could still slide down the casing without issue.

Finally, due to a lack of foresight in planning out the dimensions of the casing and heat probe, we discovered that the tip of the heat probe would not be high enough above the top of the casing when it was at full depth in the regolith. Due to this, the team manufactured a custom extension plate for the heat probe to mount the heat probe assembly higher above the actuator carriage. This extension plate now allows the heat probe tip to clear the top opening of the casing.

Challenges

When developing the concept for a casing to use in our extraction machine, we were torn between whether to use a casing or not. This was due to the assumption that the simulated surface for the competition would stay rigid due to the ice being kept well below freezing. However, after much deliberation we decided that it would be a safer path if we included a casing for the hole we were drilling with the auger. This then lead to us comparing three separate designs, but ultimately deciding on our spinlock casing design to be our choice. This design, though simple in concept, brought with it the complexity of how to lower it down with the auger without exceeding the competition limit of 100 Newtons of downward force. This lead us to the idea of attaching a hole saw to the end of the casing in such a way that it would also drill into the simulated surface along with the auger.

Another major challenge we faced was machining the copper tip for our heat probe. In addition to having a complex geometry to machine, the material choice of copper was a significant challenge. Within our school’s machine shop, the workers have the most experience with aluminum and steel. There wasn’t any direct advice we could get for working with copper from our machine shop. Online, you can only find a lot of ballparked numbers that say something like use a speed of anything between 700-2000 rpm which is a large range for machining. Everything the team could find say was just pay attention and go slow. Luckily, one of the newer teachers in our Mechanical department is a great and experienced machinist and was able to give the team some real numbers for what to use on our CNC operation. He would also come and check up on the team during machining and check our progress and give advice based on what he saw. The issues that we faced in the machine shop were all due to copper high heat conductance. After even a short tool operation, the copper begins to heat up so much that the chips that the tool is taking off don’t eject well. The heat causes the chips to almost weld together forming a ball of gunk that then gunks up the tool tip. We broke a couple of ⅛ in end mills during the CNC operation and the lathe operation took a significant longer amount of time to machine on the copper when compared to the aluminum prototype we made.

One of the biggest hurdles we had to face in our design process was delays in receiving critical parts. Most importantly, our linear actuators took more than 3 weeks longer to arrive than was originally expected. Because of this, we had to use a rudimentary drilling rig built from materials from last year’s team for most of our preliminary testing. Therefore, we were only able to test one tool at a time, and we could not assemble our full rig until the actuators arrived. Also, we were not able to design and manufacture our heat probe and drill mounts until the actuators arrived since we could not confirm the physical dimensions and layout for the actuation system. This fact severely limited the amount of time we had to test our fully mounted system.

Overall Strategy for the Competition

During the RASC-AL competition, team MINERS aims to maximize our water collection in several ways. First, we are using tools that are optimized for each material layer. The auger is a tool that is specifically designed to remove soil, and the heat probe is specifically designed to melt and collect ice. Because of this, there are no tools used in environments to which they are not designed. Another way we can maximize our ice collection is to be running drilling and melting operations at the same time. While the heat probe is melting ice in the first hole, the auger can be drilling a second hole at the same time. This way, there is no wasted time while we wait for the ice to be collected from the first borehole. Finally, we are able to precisely control what our system is removing from the the surface and what is below. Thanks to that, we are able to be calculated in our approach and ensure that our system is not over removing ice that will eventually lead to a collapse. With our design, there is no wasted water. Anything that we melt can be extracted. We are not losing any to ice chunks falling off an auger bit or by allowing water to mix with the clay at any point. By using these design facets to our advantage, we aim to show that our design is the most efficient water extraction system in the competition.

Summary of Integration and Test Plan

Team Miners is currently in operation and testing of our excavation system. During our dry run test, we had full functionality of all subsystems. As seen in Figure 6 we placed our system over a bucket filled with compacted roglith using two separate tables. We are able to alter the plunge rate of both the heat probe and the drill simultaneously. This will allow us to collect water from one hole while the other hole is being drilled. During our testing we have discovered that we will have to adjust the speed of the drill motor to match the plunge rate for water ever conditions we are given. Currently we are using a drill speed of 0.013% duty cycle and plunge rate of 500 hz in order to keep the motor from stalling and burning out. This will be a challenge during competition but we are confident that we will be able to find the optimal drill speed as well as plunge rate for whatever conditions we are presented. We have designed our auger system so that the casing can reach a maximum depth of 0.6 m and can still remain well above the borehole so that excess material will not fall back into the hole. While testing without the casing we discovered that the penetration rate of the auger is much more rapid while the borehole walls maintained stability. This allows us to decide whether or not the casing will be required during competition. The current labview code contains four fully operational blocks that control the speed/direction of all three actuators and the speed/direction of the drill. All four can be adjusted using either a dial or a numeric input. Our code also contains a switch that allows us to turn on the drill motor and the drill actuator simultaneously. Currently we have our signals from the load cell amplifiers and the non-invasive current sensor outputting a waveform that allows us to view WOB as well as total current usage from the entire system. This can be viewed graphically and numerically on the LabVIEW front panel. WOB is monitored separately for the heat probe and drill using different load cells. The other dry run tests proved successful. The heat probe test shows that we have full actuation control of both lateral and vertical movement as well as actual remote heat control. The heat rope in the copper tip can be activated using a switch. The pump test was successful and proved that we will be able to extract water once the heat probe has started its melting process. Once the pump and heat rope are activated, they operate at full power. The heat probe temperature can also be monitored using a thermocouple. The temperature is output in Celsius and graphed against real time. All figures for the dry run can be found in the Appendix in Figures 5-9.

For the future, the team will have to do a longer test time on the heat probe melting process. The team is currently unaware of what prolonged exposure to high temperatures will do to the entire heat probe assembly. The high temperatures might cause an overheating problem of the wires leads that are providing the power, it could melt the vacuum tube, or it could even cause the actual heat rope to overheat. Under the current testing conditions, we have seen no chance of failure, but the team would like to ensure that we have a contingency plan if overheating is going to be a significant factor. Further testing will also need to be done to find the best operating speeds for the drill motor speed and the actuator speed. Further testing of the load cells also needs to be done on both the heat probe and drill in order to ensure that we have properly calibrated both cells and are receiving accurate and useful data.

Tactical Plan for Contingencies/Redundancies

In order to mitigate potential risks during the duration of the competition, the team plans to bring extra parts for critical pieces that may break. First of all, the team will bring extra bolts and screws for all critical connections in case they shear from large loads. These include screws for the casing connections, heat probe assembly, and actuator mounting plates. This way, the team can repair any mechanical connection in case of failure. Another step the team will take is to bring extra fuses, wires, and electrical connectors in case of power surges and electrical shorts. The team will bring a soldering iron to repair wire connections as well. By planning for such electrical failures, the team will decrease the risk of having our drilling rig being put out of commision for a large part of the competition. Finally, the team plans on bringing extra filters in case they fail or get too clogged to pull any more water. This way, the team can quickly replace a filter to continue water extraction operations.

Project Timeline

Table 2: Project Timeline

Task #	Task Description	Start	Finish	Duration (Days)
1	Initial Concept Generation	10/3/2017	10/11/2017	8
2	Determine Design Subsystem	10/11/2017	10/16/2017	5
3	Concept Feasibility Calculations	10/16/2017	11/14/2017	29
4	Low Cost Prototype and Mockup Testing	10/16/2017	11/14/2017	29
5	Concept Critique and Final Design Decision	11/7/2017	11/14/2017	7
6	Create CAD Drawings of Subsystems and Assembly	11/14/2017	1/9/2018	56
7	Project Plan Submittal	11/16/2017	11/16/2017	0
8	Setup Drilling/Auger Test Rig	11/21/2017	11/30/2017	9
9	Begin Testing and Data Collection for Heat Probe and Extraction Systems	11/28/2017	12/7/2017	9

10	Begin Testing and Data Collection for Drilling System Using Test Rig	11/30/2017	12/7/2017	7
11	Construct Frame and Actuation Systems	11/30/2017	3/26/2018	116
12	Develop Control System Using LabView	2/28/2018	5/10/2018	71
13	Finalize Subsystem Designs	1/9/2018	2/22/2018	44
14	Prototype Heat Probe and Extraction Assembly	1/29/2018	4/23/2018	84
15	Film Video of System Ability	3/8/2018	3/11/2018	3
16	Mid-Point Progress Report Submittal	3/11/2018	3/11/2018	0
17	Preliminary Testing of Overall Ice Extraction System	3/15/2018	3/29/2018	14
18	Integrate Subsystems Into Final Assembly	3/26/2018	4/23/2018	28
19	Resolve Issues Found During Testing	4/16/2018	5/18/2018	32
20	Perform Failure Analysis and Purchase/Manufacturer Spare Parts	4/19/2018	5/18/2018	29
21	Finalize Design and Test	4/19/2018	5/20/2018	31
22	Create Wiring Diagrams for Electronics	5/4/2018	5/10/2018	6
23	Technical Paper and Integration Document Submittal	5/20/2018	5/20/2018	0
24	Mars Ice Challenge Competition	6/5/2018	6/7/2018	2

Safety Plan

The MINERS drilling system does not contain any hazardous chemicals. In order to mitigate electrical hazards, proper insulation and grounding will be used on system wiring. Insulation has been especially addressed regarding the contact of the heat probe with the water/ice. Fuses have been placed on all large electrical parts to prevent damage to the pieces and ensure the safety of the operators. Due to high rotational speed of the auger and casing, it is possible that dirt or ice could be thrown outwards at high velocity during drilling operations. Therefore, the team will wear protective eyewear during the competition.Finally, the control system will contain emergency stops for all mechanical and electrical systems in case of catastrophic failure.

Path-to-flight:

Mars presents an entirely new challenge for the drilling rig. The gravity on Mars is 38% that of Earth, and the atmospheric pressure on Mars is only 0.006 atm (0.607 kPa), less than 1% of Earth's atmosphere [1]. With this low of pressure, ice simply sublimates when exposed to the Martian atmosphere. This is a serious problem with our current system as we would lose most, if not all, of the melted ice to sublimation. Once the auger is pulled out of the hole, the ice is left exposed to the atmosphere. The ice would begin to sublimate at a slow rate, much like dry ice (solid CO2) sublimate on the surface of Earth. The amount of water lost during the time between auger withdrawal and heat probe insertion would be very small and, in some cases, none would sublimate at all. As you can see from the water phase diagram in Figure 3, water at the average Martian temperature and atmospheric pressure is actually solid. The "M" on the chart indicates Mars. However, this is an average from the entire planet, including the poles where temperatures dip quite low. Right now, NASA does not find landing at the poles practical and would prefer to land between the latitudes of -50 and 50 degrees [2]. Thus, our drill can expect warmer temperatures that would cause sublimation, at least during the day, but not temperatures such that the amount of sublimation would be significant. However, this all changes when the heat probe is inserted. The significantly higher temperature of the probe would put the natural state of the water well into the vapor section of the phase diagram (Figure 3). The ice near and in contact with the probe would be turned into vapor. And since our design has a probe that is ¼" smaller than the auger, the water vapor would easily escape out of the hole.

Our pump would also struggle to work in this atmosphere as it requires a back pressure in order to pull water in and a denser composition of air to create suction. Small amounts of the vapor created by the heat probe may be captured by the pump but the vast majority would be lost to the atmosphere. Thus, the pump would be completely ineffective on Mars.

To solve these problems, our team proposes creating a closed system to capture sublimated ice, as seen in Figure 2 below, instead of trying to collect the water in liquid form. The pump would be eliminated altogether and the hole in the end of the probe would be closed up. We would rely on a closed, dome-like structure to gather almost all the ice as it sublimates from below the Martian surface. The sublimated water would then be pumped using a compressor into a pressurized chamber where it would condense into liquid water. The chamber would be temperature and pressure regulated to ensure that the water remains liquid. The exact temperature and pressure within this container would be dependent on the use. If this drill was connected up to a human habitat, bring the water to Earth's temperature and pressure would make it available for immediate use within the habitat. For other uses, a lower temperature and pressure in which the water is still liquid may be preferable as it would take less energy.

The water collected using this system would contain very little if any sediment. The sublimation process would leave behind any dirt particles in that happen to be in the water. This leaves the water quite clean and easy to manage. The extensive filtering system that we have implemented on our Earth system would be unnecessary. The water still may have to be purified as scientists have found that bacteria can survive within ice. Of course if bacteria is indeed found in the water, this is a massive discovery, proving life exists on Mars. Purification would take place as necessary and would happen outside of our drilling system. NASA's current purification system is the size of a cigarette package. Some uses of the water, such as for fuel, would not require purification while others, such as for drinking, would require extensive purification. Since the water is at Earth conditions, conventional purification methods would work. For the low flow rates that our pump produces, filters like the commercially available Sawyer water filter used in our system would work well.

Another path-to-flight step that would have to be taken is mounting the drilling system onto a rover instead of a stationary frame. This way the rover could move around to any drilling location it deems suitable for water collection. Adding a wireless control system would also be critical so that the drilling rover could be remotely controlled by signals sent from Earth, or astronauts could control it from their base or landing vehicle.

Other modifications to be made, would be to put some form of renewable energy on our system, be it solar panels that run the system, batteries that use solar panels to charge, or possibly a fuel cell and electrolysis machine to power our extraction system. Each of these changes to how we power our extraction system comes with their own benefits and complications due to the nature of the environment that the system is being implemented in. using just solar panels to run our system would be quite easy due to the rover it would be on having its own solar panels to power its other systems. The drawback to just using solar panels is that the rover may not have enough power to perform other operations while it is extracting water from the martian surface. As such, using solar panels and batteries would be a much more efficient solution to the power issues. During the day, the solar panels would run most of the day operations and charge up the batteries, so that at night the rover and extraction system would still be able to function. Though the downside to this idea is that batteries can only be charged and discharged so many times before they have some of the cells failing, thus making the battery unable to function. A third option for powering our extraction system and rover would be to use a fuel cell and an electrolysis machine to use a little bit of the water extracted to power the rover. By using a fuel cell and an electrolysis machine, we can create our power using some of the water we collected to start the fuel cell and then the electrolysis machine would split our water into hydrogen and oxygen, which then powers our fuel cell. This method might take more management and time to get started but it will have the most consistent pay out in terms of power out of the three options we thought of.

By performing these modifications, our drilling system could successfully extract water from a real-life Martian environment to support human missions on the Red Planet.

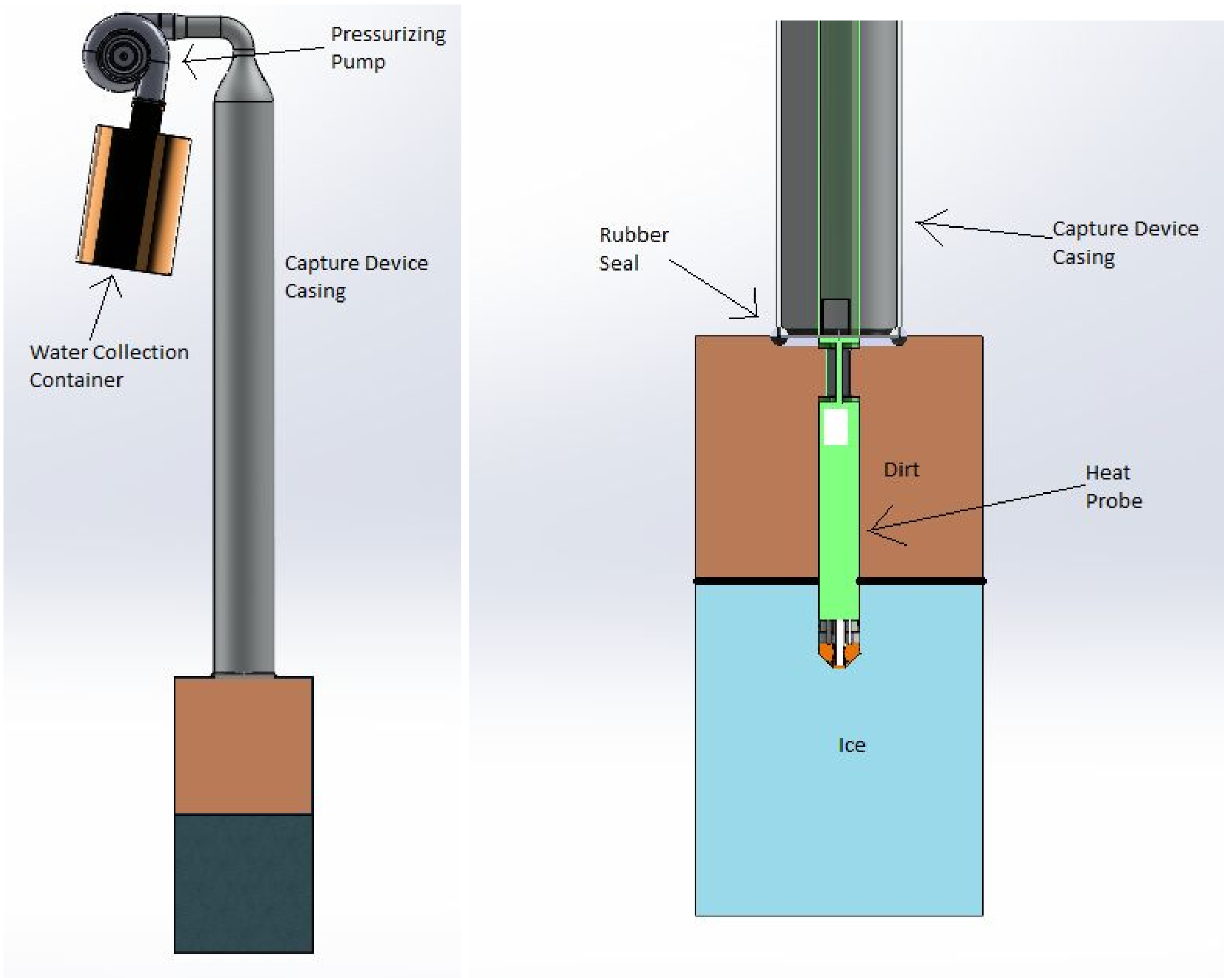


Figure 2: Concept Drawing of Mars Adaptation for Drilling Rig

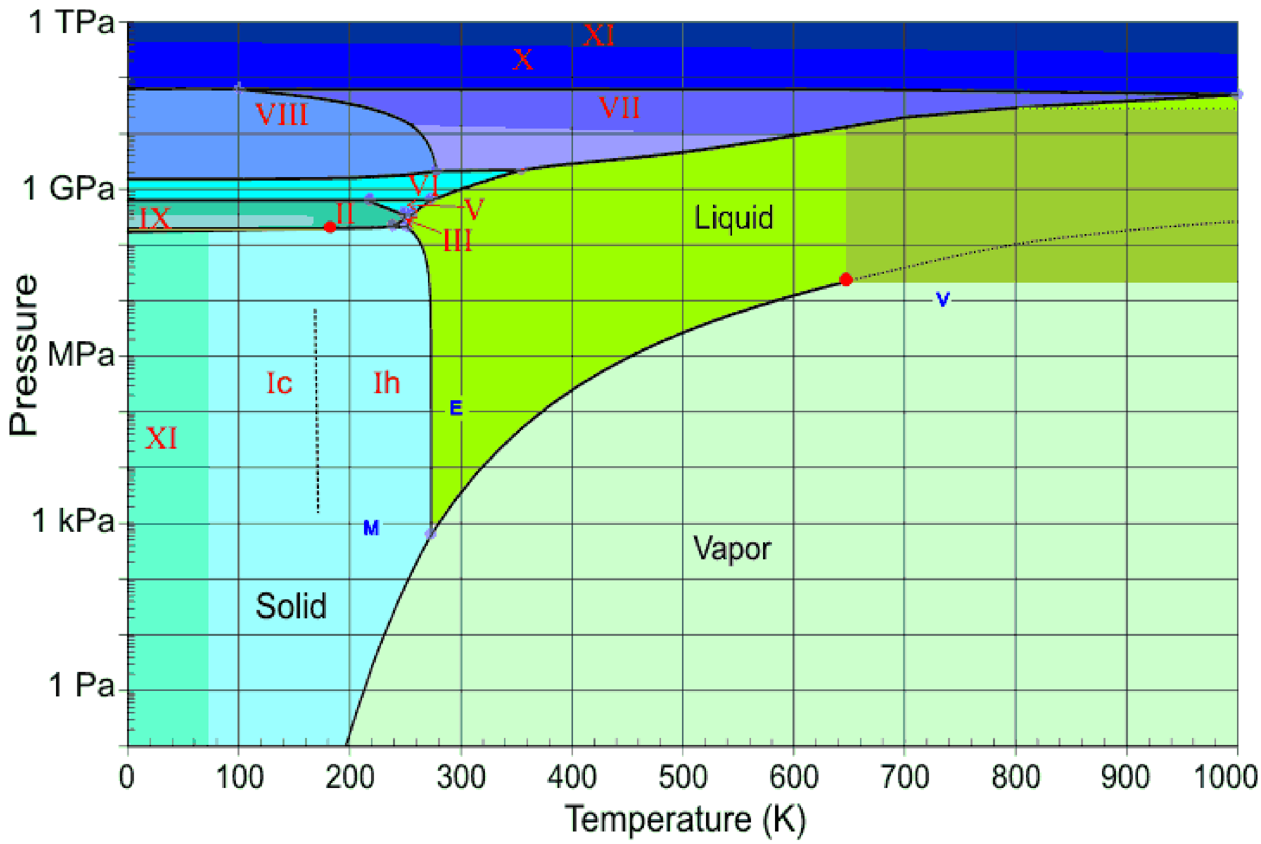


Figure 3: Water Phase Diagram with Earth, Mars, and Venus indicated [3]

Budget

For the budget, the team would like to express its gratitude to the National Institute of Aerospace for the generous stipend provided for the competition. The team would also like to thank the Senior Design program at the Colorado School of Mines for providing a starting budget for the competition. The money provided was enough to cover all costs, and estimated costs of shipping, associated with the competition without the need for outside funding. The team has also received the myRIO and the load cell from the previous team as a donation, which totaled to $900 according to their budget. The budget from the Senior Design Funds and the NASA funds are provided below in Table 3 and Table 4 respectively.

Table 3: Detailed Budget out of Senior Design Funds

NASA Mars Ice Drilling Challenge (Senior Design)				
Date	Description	Cost/Revenue	Total Cost	Remaining Balance
8/24/2017	Project Start	$ -	$ -	$ -
10/3/2017	Starting Budget provided by school	$ 4,000.00	$ -	$ 4,000.00
11/30/2017	Frame Purchase (Frame Purchase Form)	$ (320.74)	$ 320.74	$ 3,679.26
11/30/2017	Heating Rod Purchase (Mars - Rope & Tape Heaters Purchase)	$ (94.00)	$ 414.74	$ 3,585.26
12/5/2017	Pump Purchase (SD Purchase Form - Pump and Piping)	$ (334.67)	$ 749.41	$ 3,250.59
1/18/2018	Clay and Bucket Order (Tanner Petty Cash Form)	$ (45.66)	$ 795.07	$ 3,204.93
1/19/2018	Actuator Purchase (Signed Actuator Ordering Form 1)	$ (794.41)	$ 1,589.48	$ 2,410.52
1/23/2018	Cable and Terminal Purchase (Mars - Tools and Wire and Ammeter)	$ (63.15)	$ 1,652.63	$ 2,347.37
1/25/2018	Filter and Piping Stuff (Mars - Filter and Piping Stuff 1-25-18)	$ (156.55)	$ 1,809.18	$ 2,190.82
1/25/2018	Nuts and Bolts Purchase (Ordering Form 1_25 25-Jan-2018 10-35-17)	$ (248.54)	$ 2,057.72	$ 1,942.28
2/16/2018	Clamp and Mounting Kit Purchase (PBC Linear ordering 2_16 16-Feb-2018 10-52-15)	$ (86.62)	$ 2,144.34	$ 1,855.66
2/21/2018	Actuator Purchase 2 (Mars - PBC Actuator Ordering 2_19 Actual)	$ (1,508.56)	$ 3,652.90	$ 347.10
3/16/2018	Final Heat Probe Build Purchase (Mars - Copper Aluminum and Rope Heater)	$ (213.12)	$ 3,866.02	$ 133.98
3/22/2018	Aluminum Tube Purchase (Mars - Aluminum Tube)	$ (56.56)	$ 3,922.58	$ 77.42
4/19/2018	Poster Print	$ (20.00)	$ 3,942.58	$ 57.42

Table 4: Detailed Budget out of NASA Funds

NASA Mars Ice Drilling Challenge (NASA)				
Date	Description	Cost/Revenue	Total Cost	Remaining Balance
8/24/2017	Project Start	$ -	$ -	$ -
12/15/2017	Starting Budget provided by NASA	$ 5,000.00	$ -	$ 5,000.00
3/20/2018	Final 80/20 Purchase (8020 Ordering Form 3_20(Order Form))	$ (316.67)	$ 316.67	$ 4,683.33
3/30/2018	McMaster Carr Purchase (Receipt 59912091)	$ (25.93)	$ 342.60	$ 4,657.40
4/2/2018	Gempler's Auger Purchase (Order #W63C25BF5C65 _ GEMPLER'S)	$ (116.98)	$ 459.58	$ 4,540.42
4/3/2018	SparkFun Order (SparkFun)	$ (82.73)	$ 542.31	$ 4,457.69
4/3/2018	Aluminum Tube Purchase (Online Metal Store _ Small Quantity Met...tal Product Guides at OnlineM	$ (66.33)	$ 608.64	$ 4,391.36
4/5/2018	Hilti Rotary Drill Purchase (Hilti_CS Cash Sale_26013724)	$ (329.00)	$ 937.64	$ 4,062.36
4/5/2018	Drill Adapter (Home Depot.PNG)	$ (39.97)	$ 977.61	$ 4,022.39
4/12/2018	Hose Purchase (Cole-Parmer Hose Purchase)	$ (27.49)	$ 1,005.10	$ 3,994.90
4/12/2018	Aluminum Stock Purchase (Metal Purchase.PNG)	$ (53.94)	$ 1,059.04	$ 3,940.96
4/12/2018	McMaster Carr Filter Purchase (Receipt 60837082)	$ (79.02)	$ 1,138.06	$ 3,861.94
4/12/2018	Amazon Pump Purchase (Amazon Pump Purchase.PNG)	$ (66.50)	$ 1,204.56	$ 3,795.44
4/16/2018	Relay Purchase (Ebay Order 1.PNG)	$ (8.61)	$ 1,213.17	$ 3,786.83
4/16/2018	Relay Purchase (Ebay Order 2.PNG)	$ (10.78)	$ 1,223.95	$ 3,776.05
4/16/2018	SparkFun Lights Order (Sparkfun Lights)	$ (28.15)	$ 1,252.10	$ 3,747.90
4/16/2018	AdaFruit Electronics Purchase (AdaFruit Electronics.PNG)	$ (28.60)	$ 1,280.70	$ 3,719.30
4/17/2018	Wire Purchase (Ebay Wire Purchase)	$ (77.39)	$ 1,358.09	$ 3,641.91
4/17/2018	Metal Plate and Pipe Purchase (Online Metal Plate and Pipe.PNG)	$ (82.13)	$ 1,440.22	$ 3,559.78
4/19/2018	8020 Ordering (8020 Ordering April 19)	$ (30.82)	$ 1,471.04	$ 3,528.96
4/30/2018	Online Metals Aluminum Plate Order (Online Metals Sheet Metal)	$ (37.40)	$ 1,508.44	$ 3,491.56
4/30/2018	Amazon Electronics Purchase (Amazon.com - Order 112-3180633-0881053)	$ (35.88)	$ 1,544.32	$ 3,455.68
4/2/2018	Passed NASA Mid Project Review	$ 5,000.00	$ -	$ 8,455.68
4/18/2018	Hotels Cost	$ (1,236.00)	$ 1,236.00	$ 7,219.68
5/8/2018	Registration Fee	$ (1,650.00)	$ 1,650.00	$ 5,569.68
5/8/2018	Flight Cost	$ (2,323.00)	$ 2,323.00	$ 3,246.68
5/16/2018	Final Sparkfun Electronics Order (Final Electronics Sparkfun)	$ (59.32)	$ 59.32	$ 3,187.36
5/20/2018	Shipping Estimate Cost	$ (1,000.00)	$ 1,000.00	$ 2,187.36

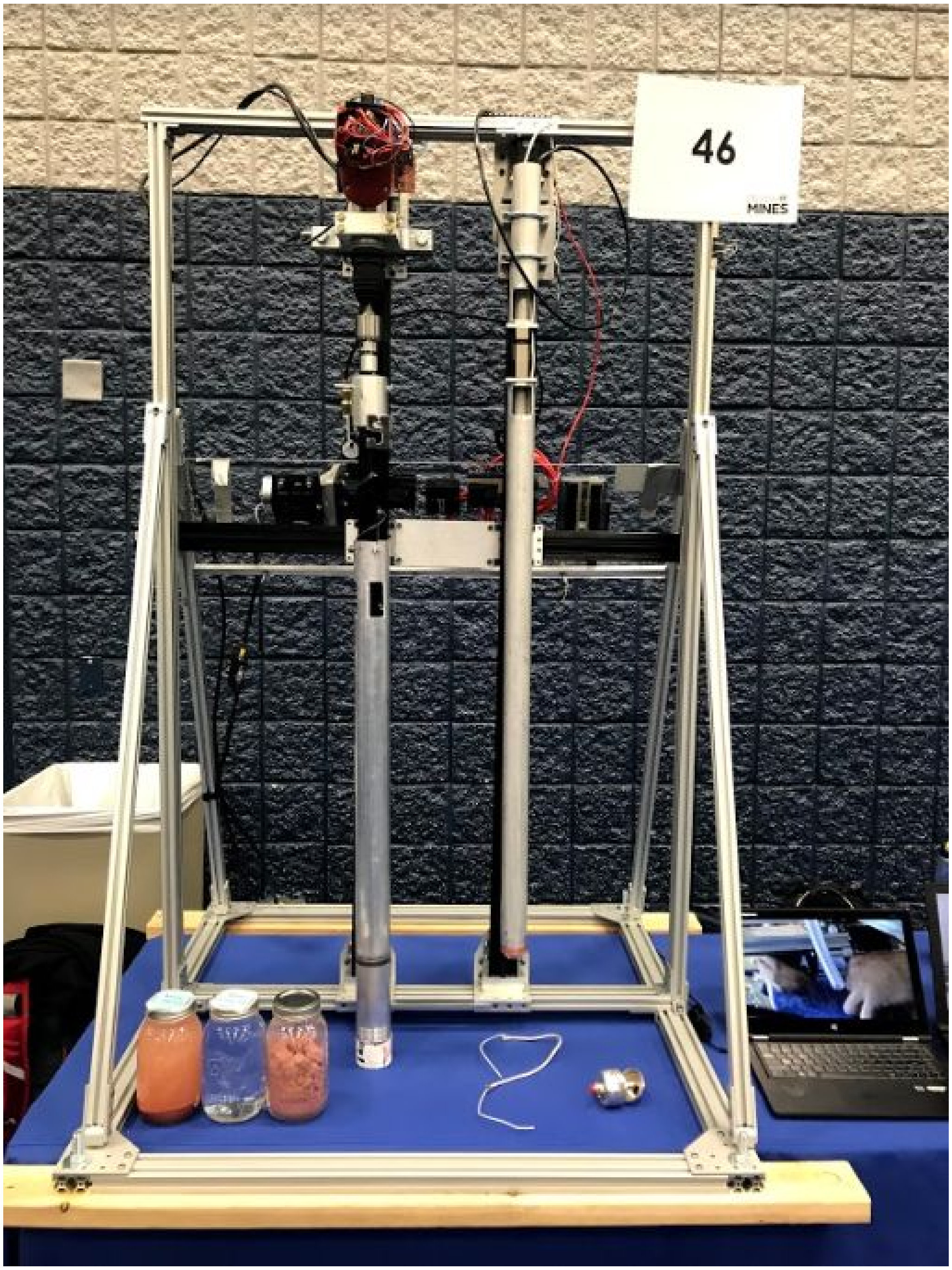
References Cited

[1] D. Williams, "Mars Fact Sheet", *Nssdc.gsfc.nasa.gov*, 2018. [Online]. Available: https://nssdc.gsfc.nasa.gov/planetary/factsheet/marsfact.html. [Accessed: 02 - May- 2018].

[2]Hoffman, Stephen, et al. "'Mining' Water Ice on Mars An Assessment of ISRU Options in Support of Future Human Missions." NASA, July 2016. https://www.nasa.gov/sites/default/files/atoms/files/mars_ice_drilling_assessment_v6_for_public_release.pdf

[3]http://webhome.phy.duke.edu/~hsg/363/table-images/water-phase-diagram.gif

Appendix



Figue 4: Picture of Final Design

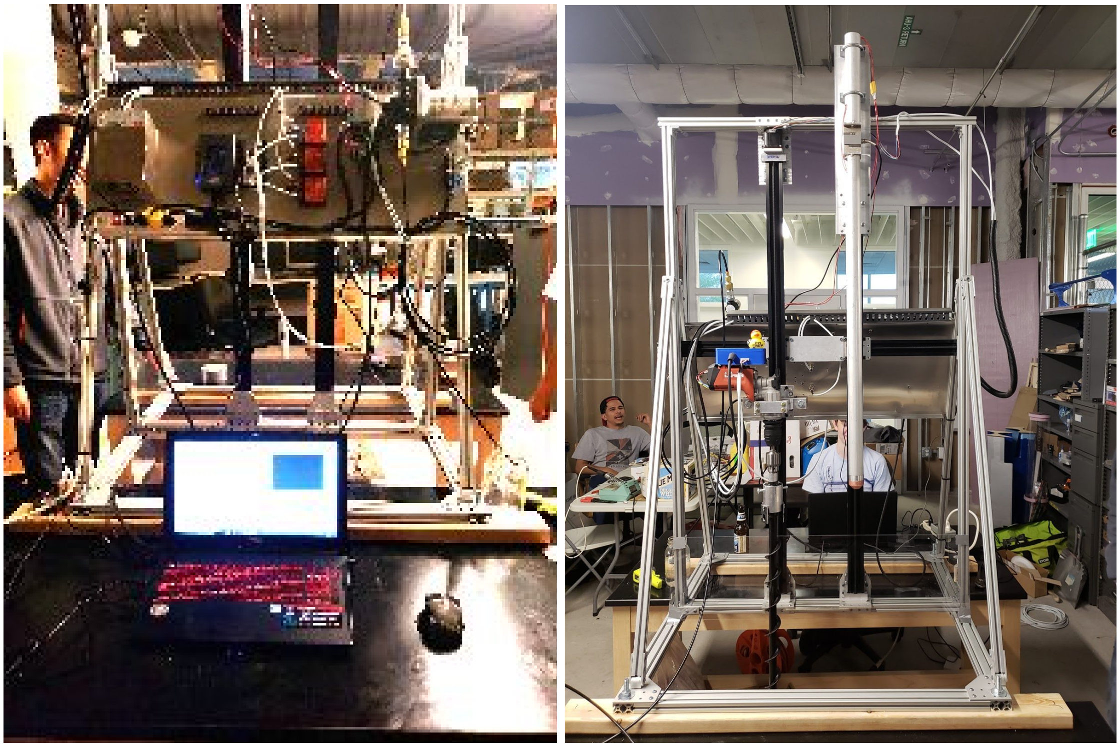


Figure 5: Final Assembly with Electronics Layout, Wiring Organization and LabView

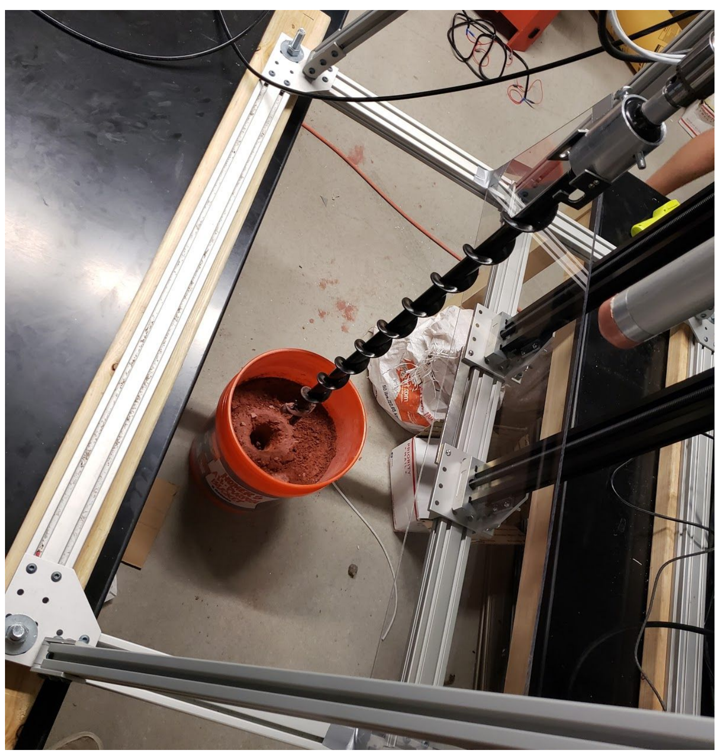


Figure 6: Dry Run Tests Drilling

Figure 7: Dry Run Drilling Tests Results

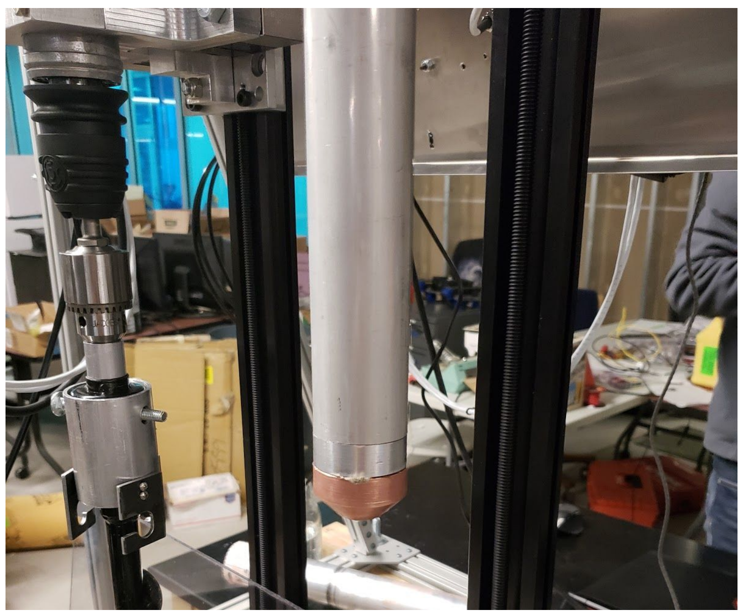


Figure 8: Final Heat Probe Assembly

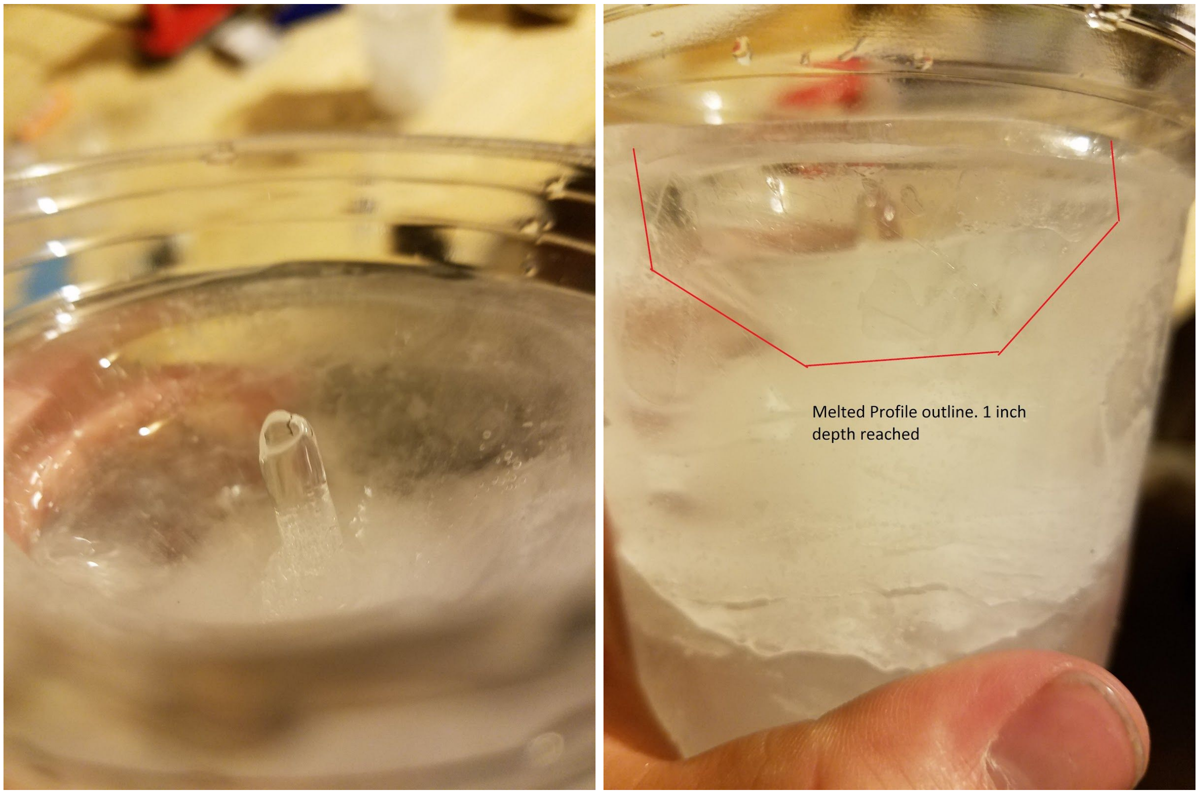


Figure 9: Dry Run Ice Melting Test Results