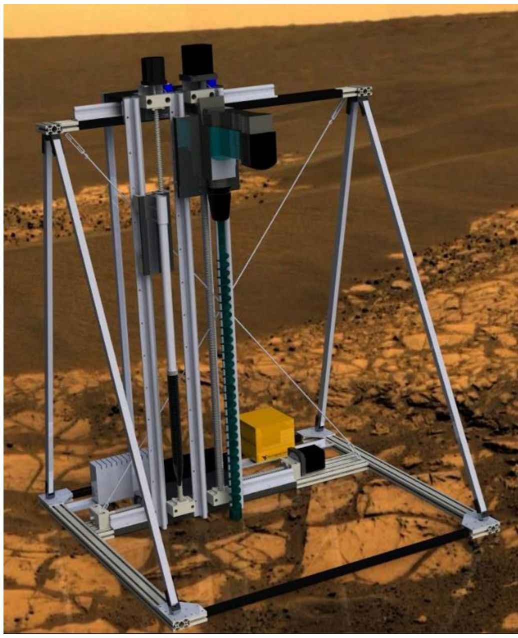
2017 RASC-AL Special Edition: Mars Ice Challenge



Technical Report

West Virginia University

Statler College of Engineering and Mineral Resources

The Mountaineers – Team MIDAS

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1 Introduction

The importance of robotics in space research and applications has never been greater. As mission complexity and duration exceed the physical capabilities and limitations of human astronauts, the only logical solution is to employ the use of robotics. Using robots on the front-line of space exploration facilitates longer mission durations, eliminates humans from danger, and reduces costs. Whether a robot is operated remotely or autonomously, their usefulness in accelerating space exploration has been proven many times over the past several years, especially with the rovers *Spirit*, *Opportunity*, and *Curiosity* currently on Mars. NASA competitions capture the heart of this idea and bring teams together from across the country to compete and learn from one another.

The 2017 Revolution Aerospace Systems Concepts Academic Linkage (RASC-AL) Special Edition: Mars Ice Challenge serves to challenge collegiate teams in the design and development of a planetary drilling rig to extract water from a Martian testbed at NASA Langley Research Center (LaRC). The West Virginia University Mountaineer Ice Drilling Automated System (MIDAS) team awaits our visit to NASA LaRC in June. The Mountaineers are confident they will have a fully functioning prototype and be capable of an on-site performance. After some setbacks with shedding excessive weight on our drilling system, the team is practically finished with the production stage of the final frame/drilling system and is currently in the final validation stages.

The foundation of MIDAS is a mobile hammer drill on a linear rail equipped with an auger style concrete bit for drilling operations. The selected motor and bit allows the rig to reliably drill through the ice and overburden layers at any densities inherent to the simulated Martian testbed under various compaction and temperature conditions. The extraction system, which is on its own rail beside the drill, consists of an electric heater and pump for the melting of ice and withdrawal of the target liquid. A low-power embedded computer system processes a comprehensive suite of sensory systems to facilitate real time monitoring and manual control from a remote location via a tethered line.

The Mountaineer Robotics Team (MRT) comprises graduate and undergraduate students from a variety of disciplines and backgrounds. Traditionally our teams have worked well together and have a history of excellence in the competitions that are chosen to participate in by winning several 1st place awards and placing high in the overall NASA competitions. Participation in these competitions has provided the critical organizational and design skills to compete in the Mars Ice Challenge. The MRT has the full endorsement and financial support of the College of Engineering and Mineral Resources (CEMR), the Lane Department of Computer Science and Electrical Engineering (LCSEE), the Department of Petroleum and Natural Gas Engineering (PNGE), and the WV NASA Space Grant Consortium to compete in the 2017 RASC-AL Mars Ice Challenge. Even though outreach was not a primary goal of this competition, the MRT has put in over 750 man hours and reached out to over 18,000 individuals across three different states to teach them about NASA, space robotics, and the team's experiences throughout these competitions.

This paper will showcase the functionality of the MRTs final iteration of the drilling rig, MIDAS. The remainder of this paper will be divided into 11 sections: system description, changes/improvements, challenges, strategy for the competition, integration and test plan, tactical plan for contingencies/redundancies, updated timeline, safety plan, path-to-flight, budget, and references. The paper will go over the drilling system to be showcased at NASA Langley, and the path to flight section will justify our design for an actual Mars mission or go over the necessary modifications that would have to be completed.

2 System Description

The design, seen in Figure 1, consists of a combination of single and double t-slot aluminum extrusion bars, composite carbon fiber structural elements, lightweight aluminum tubes, and tension cables to create a rigid platform that enables horizontal and vertical movement of the drilling and extraction systems on MIDAS. The inspiration for this specific design was an oil drilling rig. By closely mimicking the frame structure of an oil rig, the design required less material than a cube or box-like structure. The t-slot was excellent for rapidly building the test platform and yielding the strength necessary to withstand drilling procedures. The center assembly of MIDAS utilizes linear slide bearings to ride along two rails located at the top and bottom of the frame. The bottom channel is attached to a precision NEMA 24 stepper motor through a lead screw to enable horizontal motion. The first iteration of the frame, which was an all-aluminum double t-slot prototype, was much heavier than expected which justified the need for composites and hollow aluminum tubes in key locations. MIDAS meets size constraints and measures in at approximately 98 cm x 98 cm x 148 cm tall and is currently at 49.9 kg.

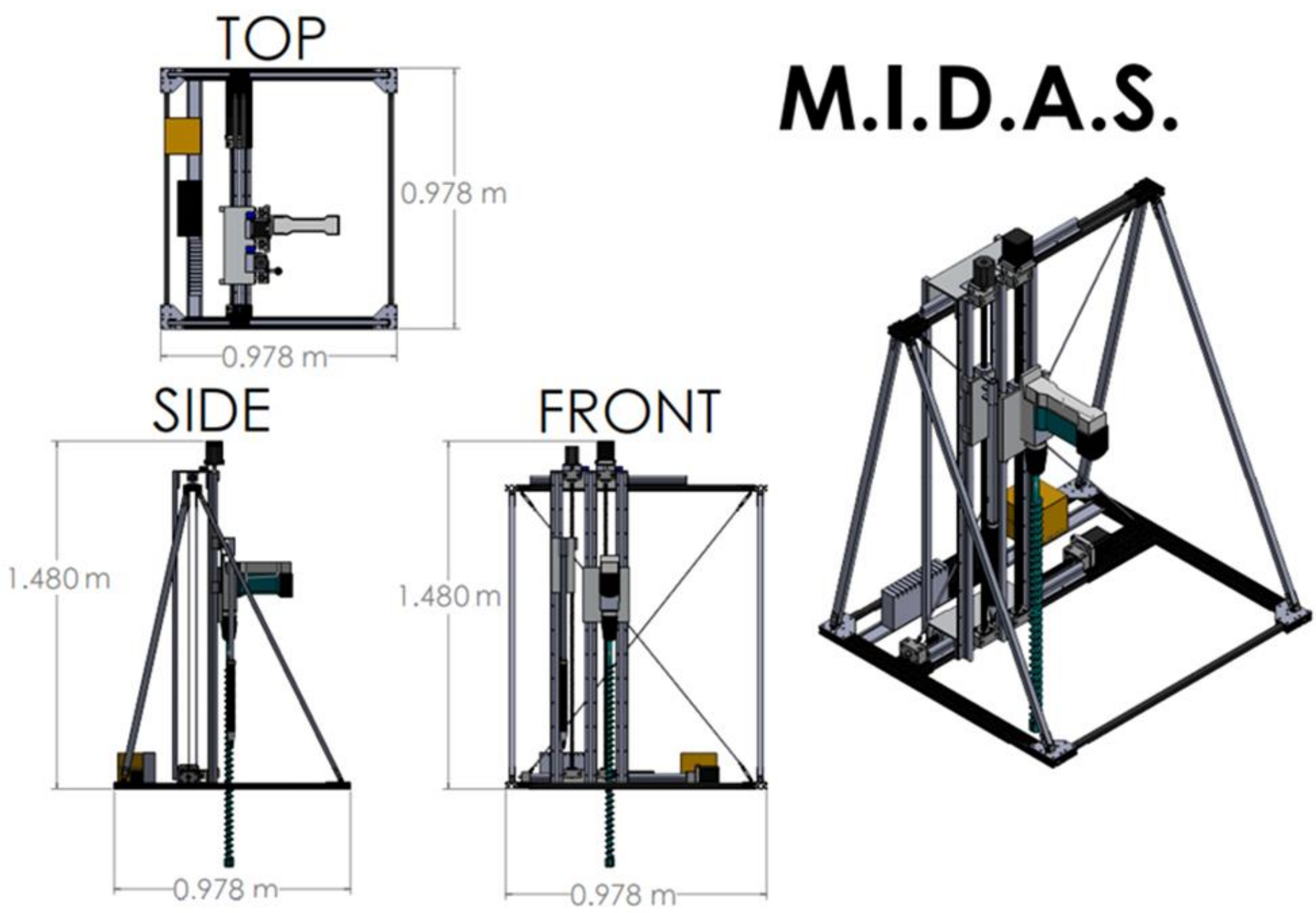


Figure 1: 3-D View of MIDAS

In a sequential fashion, MIDAS has the capability of drilling to the target depth, which is approximately 10 cm from the bottom of the polar ice box, through the overburden and ice layers, deploying a heater/pump assembly into the bore hole, melting ice for hours, and pumping the water out at the end of the day. This process can be repeated numerous times in new locations up to 23 cm away from the initial bore hole assuming the first hole is drilled at the horizontal limit that allows the heater to be translated over into the hole. A visual aid of the MIDAS sequence is shown in Figure 2 below.

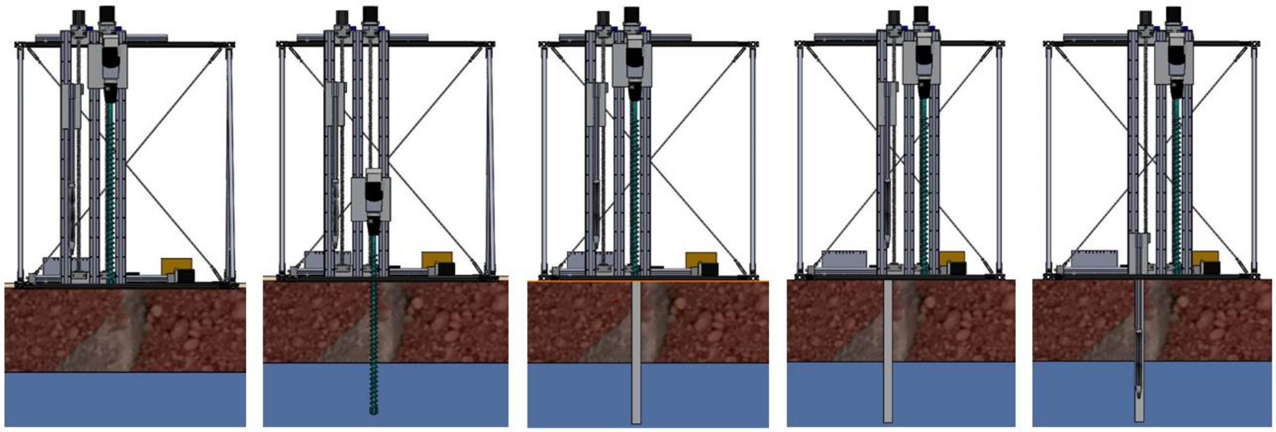


Figure 2: MIDAS Sequence

2.1 Subsytems

2.1.1 Mounting System

The anchoring system is very simple. MIDAS has holes cut into the corners of the base for mounting to the polar ice box. These holes are exactly 92.7 cm (36.5 inches per NASA requirements) apart and are oversized slightly to fit over the threaded rod coming out of the 2x4 lumber on top of the ice chest. The underneath of the t-slot corners were bored larger than the top part so MIDAS can slide over both the lock nut and the threaded rod for a level resting point on the 2x4 lumber. Wing nuts, which are shown in Figure 3, are employed to lock MIDAS in place on top of the drilling platform. Testing with our drill has shown no signs thus far of MIDAS coming loose due to vibrations and resonant conditions inherent to operating a large drill.

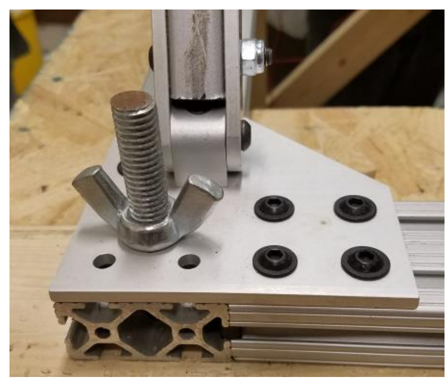


Figure 3: MIDAS Anchoring System

2.1.2 System Excavation Operations

MIDAS uses an SDS max rotary hammer drill by Makita equipped with a large concrete auger bit approximately 90 cm in length to provide quick and effective penetration through the overburden and ice layers. With the lengthy bit, MIDAS is able to drill down to the necessary depth required to effectively deploy the extraction system into the ice. A pecking operation is utilized during drilling so that the bit goes down a few cm, clears the drilled distance, and then returns to the previous depth to bore more. This is repeated until target depth is reached, much like a CNC milling machine. Drilling operations are achieved through the use of linear slide bearings that ride on two rails for vertical motion. A precision motor and lead screw combination provide the driving force necessary for this motion. The NEMA 24 stepper motor provides sufficient holding torque to keep the drill in place during down time and provides great operational torque for plunging the drill into the overburden and ice interfaces. Figure 4 shows the drill mounted to the MIDAS platform. The drill is attached to an aluminum mounting plate that is fixed to the linear slide bearings. The plate is connected to the lead screw through an S-type load cell for measuring weight on bit (WOB).

The drilling system satisfies the performance needs of MIDAS. During testing of the drill, MIDAS bored down to a depth of 20 cm in approximately five minutes, which translates to a rate of penetration (ROP) of four centimeters per minute. This indicates that the maximum depth can be reached in less than a half hour, which leaves the rest of the day for melting ice and extracting water.

Figure 4: MIDAS Drill

2.1.3 Water Extraction System

Elements of the melting and water delivery system are shown in Figure 5. Ice is melted with a 750 Watt Cartridge Heater heating element that can reach temperatures in excess of a few hundred degrees Celsius if necessary and extracted with a Flojet 5000 Series Bottled Water System. Tests have shown that the heating element can quickly liquefy ice in the surrounding area with its extreme temperature capabilities. Figure 6 shows one of our larger heating elements with an attached thermocouple sensor glowing red during a test. The thermocouple will be used to ensure that the heater remains at a constant temperature and at a safe level so the unit itself is not damaged. This current assembly is seen in greater detail in Figures 7 and 8. The heatsink is grooved for increased surface area with holes in the sharpened bottom to pump the water through. A close-up of the top shows two 750 Watt heaters, a thermocouple and an interface to force a high temperature silicone tube onto. The Flojet is strong enough to pump water from the target depth to its storage container. Both systems will be mounted together on their own linear slide beside the drilling system to allow for extraction after the boring process is complete. A rail, slide bearings, lead screw, and NEMA 23 together provide the action necessary to move the extraction system in and out of the bore hole.

Figure 5: Heater and Pump Components

Figure 6: Liquefying Process

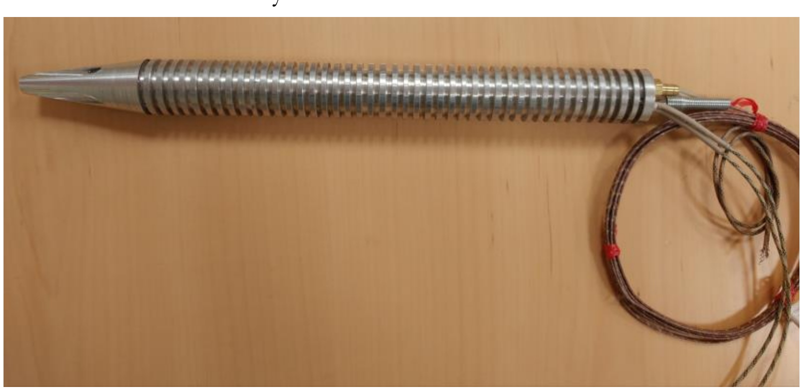


Figure 7: MIDAS Extraction System

Figure 8: Close-up of Inner Parts

2.1.4 Filtration and Water Collection

Our filtration system is very simple and consists of an inline filter on the pump that utilizes hollow fiber to separate impurities in the water. The pump can take the water either to our external collection bag or directly to the competition collection bucket itself. The MRT does not care which method is used, but we will have plenty of hose for both options.

2.1.5 Dealing with Overburden

The development of a wall casing component to keep the hole from collapsing has been terminated. Testing has shown that even a loosely packed overburden sample with just a little water mixed in is rendered to a relatively hard, cohesive material when cold. Figure 9 shows the result of a drill test on a chilled sample. The bore hole was very clean and did not require a wall casing to prevent collapses. That being said, if any overburden falls into the bore hole, it will settle to the bottom of the water in the hole during the melting procedure. Our extraction system will not pump directly from the bottom which will leave settled overburden relatively undisturbed.

Figure 9: MIDAS Drill Test on a Loosely Packed Frozen Sample

2.1.6 Bit Freeze Prevention

Due to the nature of our system, bit freeze is not a risk for us. The drill is a very powerful rotary hammer drill, and the bit is meant for boring through concrete. With the hammer action of the drill, our system breaks its way through the overburden and ice during boring procedures. This alone keeps the bit from becoming stuck. The only feasible time the bit could become stuck is if the drilling procedure was intentionally stopped inside the bore hole long enough for freezing to occur. For this reason the automated drilling procedure will never stop turning until the drill is lifted out of the hole.

2.1.7 Electrical System

The electronics subsystem is divided into several key components that work in unison to provide a stable control system for MIDAS. Figure 10 provides an updated overview of this subsystem. The main cable runs through a kill switch and delivers AC to a power bank. That in turn provides power to the DC supply and the on board computer (OBC). High current relays provide power to the drill controller, the pump, and the heater. The drill control is wired in a way to facilitate manual or computer control regarding the drill. Speed can be adjusted, the drill can be

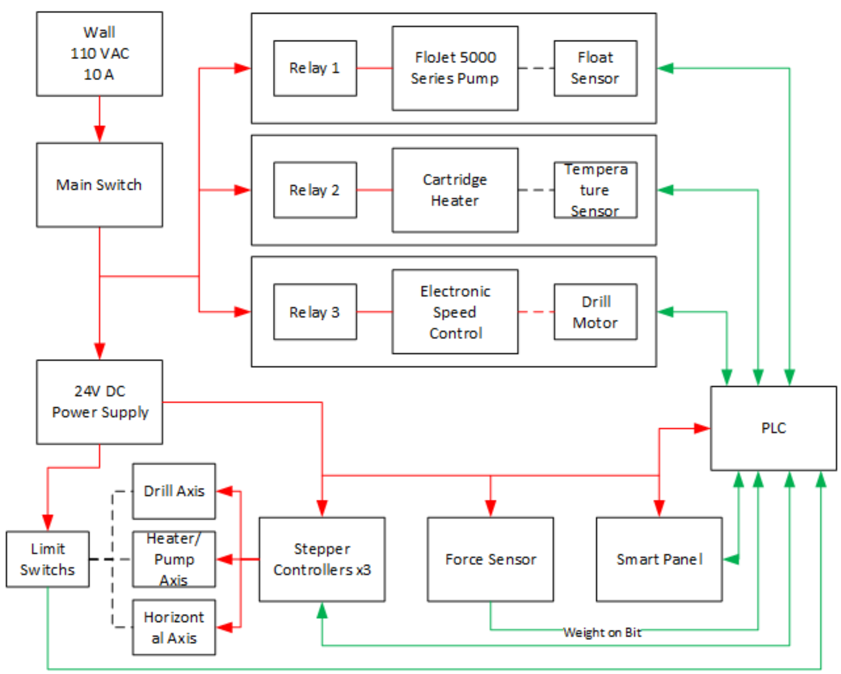


Figure 10: Overall System Diagram

switched on/off, current can be limited to a maximum value, etc. The DC supply is routed to its own power bank and provides 24 volts to the stepper motor controllers and various sensors. The stepper controllers allow the OBC to enable/disable the steppers, set direction, configure full or half current modes, configure the number of steps per revolution, and send pulses to move the motors. Parts compatible with a DIN rail were procured for ease of use and quick snap on convenience when considering this system. The complete electrical system can be seen in Figure 11. MIDAS components are wired into relays to the right of the OBC for computer control on and off. From left to right on the DIN rail are three stepper controllers, a 24V power bank, the OBC, three relays, an AC power bank, and the 24 volt DC supply. The drill motor controller can be seen on the right behind the DC supply and the load cell amplifier is lying on the bottom sliding channel. Additionally, all the wire pairs and cables on MIDAS will be routed through a raceway duct with a cover for better organization and cable management before making the trip to NASA LaRC.

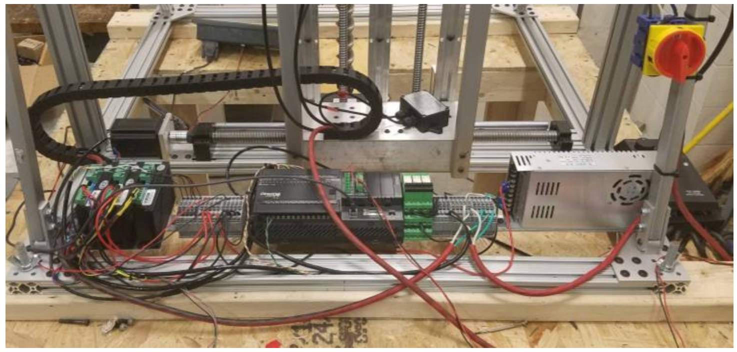


Figure 11: Fully Wired System

2.1.8 Sensory System

MIDAS utilizes limit switches to perform a homing sequence at startup. Once homing is completed the rig can effectively keep track of where it is through distance variables in the OBC. A thermocouple tied in with the heating element is monitored by the OBC to control the temperature at the ice interface, and the OBC communicates directly with all the controllers to operate the steppers and the drill. In addition to these systems the OBC also monitors a load cell on the drill mounting plate to show WOB. This configuration is shown in Figure 12.

Figure 12: WOB Load Cell

2.1.9 Control and Communication System

The OBC is an industrial programmable logic controller (PLC) by Automation Direct. The team was excited to employ this system because PLCs are used heavily in industry. Relay/Ladder logic has proven to be an interesting and effective control system for this application. All communications to the OBC are done through an interface panel shown in Figure 13. This tethered line to MIDAS will be used for manual control, automated procedures, and telemetry feedback.

Figure 13: Control Panel

2.1.10Software

MIDAS features manual control via a tethered line to a control panel for operating the system from a remote location. Software to support a fully autonomous drilling rig was a goal but has been abandoned due to the major time loss in the removal of excessive weight necessary for MIDAS to compete. Full autonomy does not exist, but there are automated procedures to facilitate easy use such as drilling to ensure MIDAS operations are not completely manual.

2.1.11 Data Logger

The PLC has limited memory but it can be used to log data for the average WOB. MIDAS will also display WOB in real time. Our drilling procedure should only last 30 minutes or less so data will not be logged for long. At the end of the day we can retrieve the data with a computer via serial port or Ethernet.

2.2 Summary of Technical Specifications

Table 1 shows a brief overview of major component specifications on the MIDAS system to give an idea of performance.

Table 1: Specifications

MIDAS	
Mass	49.9 kg
Volume	97.8 cm x 97.8 cm x 148 cm
Bit Length	90 cm
Max WOB	10 kg (98N)
Makita Hammer Drill	
Power	1000 W
Max Speed	680 RPM
Torque	14.75 Nm
Blows per Minute (BPM)	2500
Drill Stepper and Translational Stepper (NEMA 24)	
Holding Torque	3.1 Nm
Rated Current per Phase (2 phases)	3.5 A
Rated Voltage per Phase (2 phases)	3.85 V DC
Cartridge Heater	
Power	750 W
Current at 120 VAC single phase	6.25 A
Max temperature	1400 °F
Flojet Pump	
Voltage	12 V DC
Max Current Draw	1.2 A
Pump Rate	1.9 Liters per Minute (LPM)
Extraction Stepper (Nema 23)	
Holding Torque	1.89 Nm
Rated Current per Phase (2 phases)	2.8 A
Rated Voltage per Phase (2 phases)	3.2 V DC

3 Changes/Improvements

MIDAS has undergone several changes since the midpoint in the area of weight reduction. Several frame members and other supporting components were reworked and replaced with lightweight counterparts. This allowed the team to significantly shed weight without compromising the integrity of the structure or replacing our rugged motors with smaller ones.

The next change involves the heating element. Instead of just a single heater the rig now uses two 750 W Cartridge Heaters, both of which are attached to the same heatsink. The rig is also no longer fully autonomous due to the need to reduce weight along with the timing of other competitions. The rig does still have some automated procedures though such as drilling to make MIDAS easier to use.

Due to weight concerns the case wall idea has been scrapped. Through testing it was determined that a case wall was unnecessary because the hole was cleanly drilled. Another factor is that if some soil simulant does fall into the hole, it will sink to the bottom of the hole. Our water suction system does not reach to the bottom and should not pick up any of the fallen soil. Further testing has shown that the lack of a bit stabilizer significantly impacts drilling performance. "Bit walking" is problematic without one when plunging into the Martian simulant so a Teflon cylinder will be mounted to the bottom channel that rides along with the bit to reduce "walking".

4 Challenges

The largest challenge faced by the team has been the need to massively reduce the weight of the drilling rig without compromising the integrity of the system. At the time of the midpoint the rig was 10 kg overweight or more. The lab scale was reading significantly off and the team did not realize that at the time. The team started with a complete disassembly of MIDAS to cut away any excess material in non-essential structural parts. The motor mounts as well as the top and bottom aluminum u-channels were prime targets to lighten weight. The u-channels had truss patterns cut into them with a CNC mill while the motor mounts were just strategically pocket cut. During the lightening process, certain structural components were replaced with hollow aluminum tubes. 80/20 aluminum extrusion bars were machined in a way such that the open ends of the hollow aluminum tubes fit over the machined inserts on the 80/20. This allowed for lighter frame components that still fit together with our current system.

The double t-slot vertical supports were completely removed as well. This caused the rig to significantly wobble from side to side, but braided steel tension cables were employed to remedy this problem, which was still a fraction of the weight in comparison to the double t-slot. Bearing blocks at the ends of the lead screws were also milled significantly to shave more weight. The last part of the rig that was lightened was the hardened steel rails on the linear slide assemblies. The rails were swapped from hardened steel to lightweight 7075 high-strength aluminum rods. All of the above things resulted in a weight reduction from over 60 kg down to 49.9 kg, which is the current weight of MIDAS.

5 Strategy for Competition

Our strategy for the competition involves just a few steps. We will spend no more than 30 minutes drilling to a target depth approximately 10 cm from the bottom of the polar ice box at hole position one. Once the target depth is reached the remote operator will proceed with the next step, which requires the drill to be raised and translated over so that the heater/pump extraction system can be lowered into the drilled hole. Ice will then be melted over the course of five hours. The remaining time, which will be around 30 minutes, will be spent pumping the water to the competition accumulation bucket. On the second day the procedure will take place again at another hole location that can be drilled up to 23 cm away from the first hole. The results from the first day will be used to determine if our strategy needs to be adjusted. Our rig is capable of drilling multiple holes so the strategy could include drilling more than two holes if necessary. Figure 14 shows the generalized operational plan.

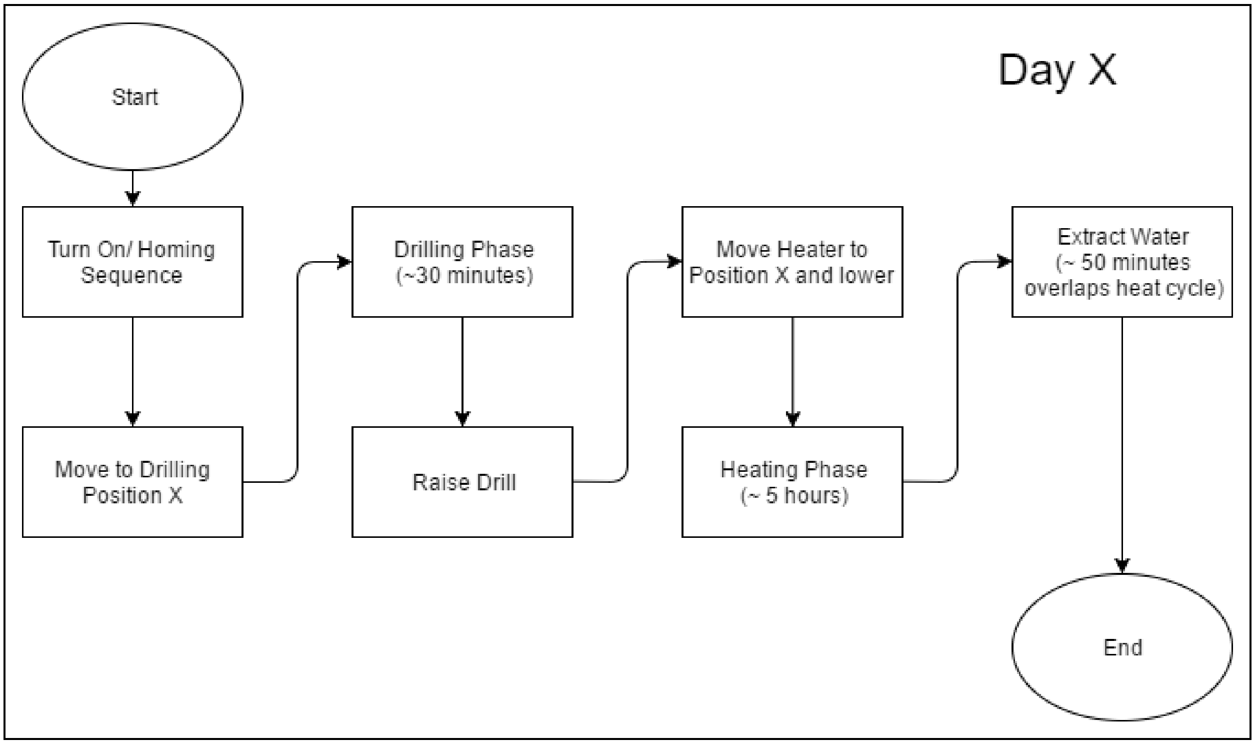


Figure 14: MIDAS Operational Plan

6 Integration and Test Plan

Simulated test results show that MIDAS will be able to melt enough ice to accumulate 27 L of water each day for a five hour melting cycle. The pumping system will require approximately 50 minutes to deliver the water to an external tank with the equipped filter. This means the time for pumping must overlap the heating cycle time. Across both days of the competition, MIDAS should be able to extract a total of 54 L of water.

Our operational test plan is to perform the set of protocols in Table 2 on the next page that our MIDAS system must have. During these protocols parameters such as WOB or current limits must not be exceeded while maintaining similar levels of performance observed in unit testing while under the complete control of the PLC in a "hands off" scenario. Operations will be deemed successful if they do the specific task under the supervision of the PLC without unexpected outputs/states occurring.

Table 2: Test Plan

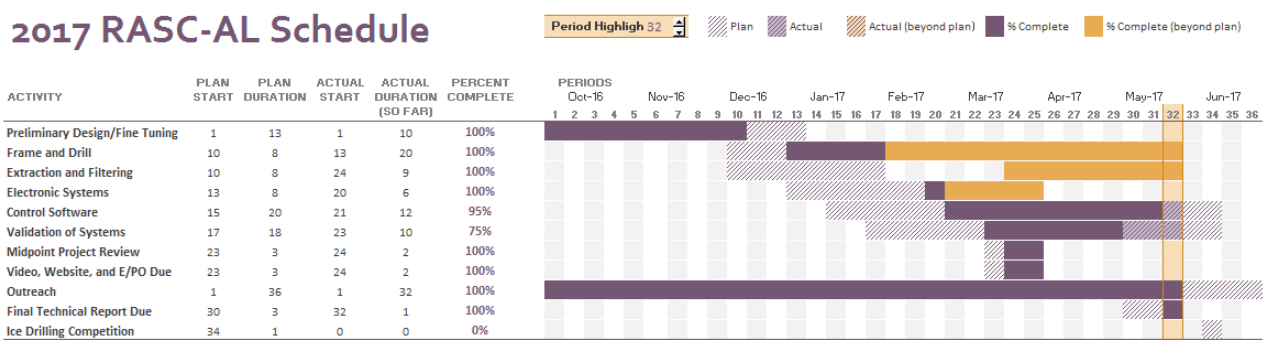
Test Name	Description	Expected Outcome	Judgement Criteria
Homing Sequence	Tests to see if the Drill and Heater system will correctly reach the proper homing location	Moves the drill and heater all the way to its upper limit as well as moving it to its extreme right limit	**Pass:** The system correctly homes each subsystem while staying under the maximum current. **Fail:** The system fails to correctly home each subsystem or exceeds the maximum current
Translate Drill/ Heater Assembly	Tests to see if the Drill and Heater system will move to the desired X position	Moves the drill and heater system to the desired X position	**Pass:** The system reaches the desired X position while staying under the maximum current limit **Fail:** The system fails to reach the desired X position or exceeds the maximum current
Automated Drill Cycle	Tests to see if the drill will follow the proper "pecking" drill cycle	The drill should remain spinning while it is lowered and raised repeatedly. This action allows for the drill to reach the desired depth while clearing debris from the hole. Upon completion drill lifts out while still spinning	**Pass:** The drill is able to reach desired depth in the allotted time while staying under the maximum WOB and the maximum current limit **Fail:** The drill fails to reach the desired depth in the allotted time or the maximum WOB is exceeded or the maximum current limit is exceeded
Automated Heat Cycle	Tests to see if the heater will follow the proper heating cycle	The heater should remain on as it is lowered into the desired hole. The heater should remain operational for the allotted time	**Pass:** The heater is able to remain on and at desired temperature for the duration of the allotted time while staying under the maximum current limit and not boiling the water away **Fail:** The heater fails to stay on for the entire allotted time or the maximum current is exceeded or the water is boiled
Extract Water	Tests to see if the pump can extract the water in the allotted time	The pump should be able to extract a majority of the water from the hole in the allotted time	**Pass:** The pump extracts the water in the allotted time while staying under the maximum current limit and delivers the end product to an external storage bucket **Fail:** The pump fails to extract the water in the allotted time or the pump leaves a majority of the water in the hole or the current limit is exceeded or the water is not delivered to the accumulation bucket

7 Tactical Plan for Contingencies/Redundancies

Unfortunately in some designs it is not always possible to have redundancies in place in the event of failure. Our weight situation limits the team as to what can be added to MIDAS, which makes it infeasible to have a redundancy in place for every potential failure point. Right now our main contingency plan is to have spare parts for all systems in the event of failure for replacement. However, after evaluating the most critical failure points, it was determined that adding a second heater as a redundancy was very desirable. The drill is very strong and rugged, which is why it was deemed a low risk. In the event that a heater burns up though, the extraction system of MIDAS will have no other way to melt ice in the hole. If one heater fails, the remaining one will be there to take melt ice. If something other than a heater fails though, it will have to be manually replaced.

8 Updated Timeline

The team's schedule is shown below in Figure 15. The remaining schedule gives the team the ability to finish the control software and validation of the entire system under a competition scenario. The schedule was pushed back many times because so much of our time and energy had to be focused on massive weight reduction. However, MIDAS is now fully developed and back on track.



ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION (SO FAR)	PERCENT COMPLETE
Preliminary Design/Fine Tuning	1	13	1	10	100%
Frame and Drill	10	8	13	20	100%
Extraction and Filtering	10	8	24	9	100%
Electronic Systems	13	8	20	6	100%
Control Software	15	20	21	12	95%
Validation of Systems	17	18	23	10	75%
Midpoint Project Review	23	3	24	2	100%
Video, Website, and E/PO Due	23	3	24	2	100%
Outreach	1	36	1	32	100%
Final Technical Report Due	30	3	32	1	100%
Ice Drilling Competition	34	1	0	0	0%

Figure 15: MIDAS Timeline

9 Safety Plan

The most prevalent safety concern with the MIDAS drilling rig is the noise created by the hammer drill. The team has not had the chance to measure the decibel level from a few feet away yet, but hearing protection is a must if one is in close proximity to the system. The loud noise comes from the shrill sound that is made when the hammer mechanism impacts the drill chuck where the bit is held. It is not as bad at low speeds, but hearing protection should still be worn. The team wants to prevent hearing loss and allow for comfortable viewing. With high speed drilling, another potential hazard is always aerial projectiles from the drilling process no matter how unlikely they may seem. The team strongly recommends safety glasses to avoid eye injury. With the heating elements capability to reach temperatures in excess of a few hundred degrees Celsius, no hands, feet, limbs, or other objects are allowed within the rig's frame. For user and observer safety, in the unlikely event that control of the drill is lost or some other unforeseen issues arise, the PLC has E-stop capabilities and there is a large kill switch on the back of MIDAS under worst case conditions. Lastly, the frame and DIN rail will be grounded along with the electronics to mitigate the risk of electrocution from high current devices.

10 Path-to-flight

The MRT believes MIDAS could perform on both Earth and Mars with minimal modifications. Ensuing information will justify Mars operations and outline major modifications. When designing an ice-drilling rig that can harvest water, there are many differences to consider between the Martian environment and the conditions on Earth. A major difference is that the atmosphere pressure of Earth is 1014 mb, whereas Mars surface pressure is 6.36 mb (0.06% that of Earth). Another concern is the temperature of the Martian atmosphere, which is around -63°C. At this pressure and temperature, the ice will sublimate from ice to vapor thereby causing issues with the water collection. Water collection will have to take place in a pressure vessel, which is exactly what we have proposed with the closed off hole, pump, and accumulation tank shown in Figure 16. Unfortunately, due to the conditions on Mars traditional pumps may not be used. Instead pumping will be replaced with heating to sublimate water vapor and then by allowing the water to condense and collect in the hole as the pressure inside our system increases, the water product can be extracted into a pressurized tank to keep it from reverting to ice or vapor. Fortunately, the triple point of water is close to the pressure on Mars, which means getting the ice to change phases and become liquid water does not require much of a pressure increase.

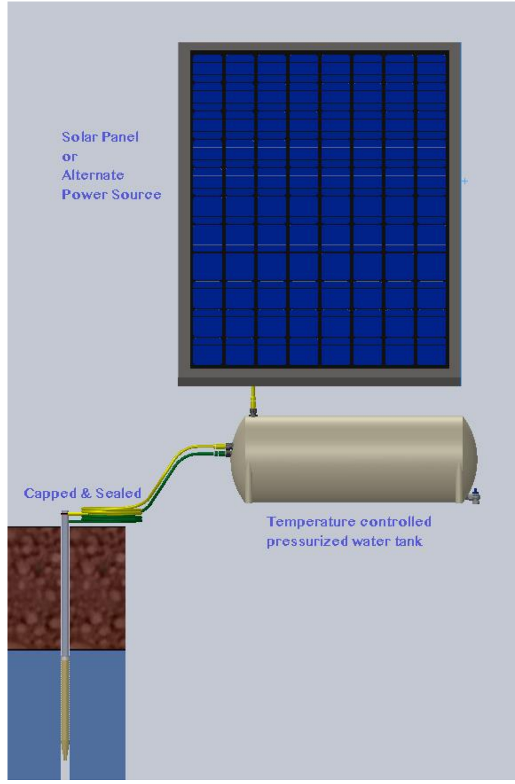


Figure 16: Closed Loop Pressurized System

Other things to consider are harsh environmental conditions such as radiation, weather, soil properties, etc. All electrical components would need shielded and replaced with radiation-hardened counterparts. Space cleared motors will need to replace the motors currently on the drill rig. A covering on our rig would also need added to protect mechanisms from windstorms and other violent circumstances. On the current rig, the hammer drill implemented uses pneumatics to generate the hammer action. Due to the lower air pressure on Mars a cam action drill will need to be used.

The MRT believes the performance of our selected drilling bit would be optimal in Martian soil. Given that Mars soil does contain some moisture, the temperature is very low, and that the terrain is uninhabited and undisturbed, we believe soil could be firm and packed instead of exhibiting a loose sand-like consistency. Our drilling system could operate in both soil types. However, for extremely dry, sandy overburden a case wall may be necessary.

Powering the system would require an array of solar panels on the outside of the rig that would charge a battery bank for drilling operations to occur daily over certain intervals. Deployment of the rig could happen in several ways. This rig could be an integral part of a rover so that multiple locations could be drilled relatively quickly, and when the accumulation tank is full, life-sustaining water could then be returned to a Mars habitat. We believe this is the most efficient deployment method on Mars, but if the rig was dropped by a rover or set up by a team of astronauts, the anchoring system could be as simple as spikes on the corners of the rig or as complicated as anchoring drills. The spikes would penetrate the initial soil layer and keep the rig from moving around. Since the drilling force is much smaller than the allowable weight of the rig, stability of the rig should not be an issue. Anchoring drills would provide the same effect, but could be retracted more easily than spikes for someone or something to fetch or drag the drill to a new location.

With the power of the hammer drill and the capabilities of the melting and extraction systems, one alternate system could be to use a single drill and many extraction systems. Whether it was by a robot or human, a separate entity would drill the holes into the surface. Due to the speed that the drill bores through the surface, many holes could be made quickly. Each hole created would then have an extraction unit placed in. These extraction units would be a combination of heating and condensation (instead of a pump) elements similar to what is present on our prototype drill rig. Then utilizing the method described above, each unit would independently collect water and then after the water is collected removed, emptied, and moved to a new hole. A system like this would be most effectively employed in an area with sparse ice. This method specializes in covering a large area where not every probe will collect a full load of water. However, it will collect as much water as possible from the ice that is available.

Another implementation would combine all three components; the drill, heating element, and pump all in one as shown in the Figure 17. Utilizing slip rings to deliver power to a heating element installed into the bit, similar to the current design, the ice would then sublimate due to conditions being near triple point and the heated water vapor would travel up a hole in the center of the drill bit. The bit and water storage units could be attached to a larger robot or a stationary rig similar to the current prototype. Due to the size of the hammer drill, a rig like this would prove most effective when there is a large amount of ice present in a small area.

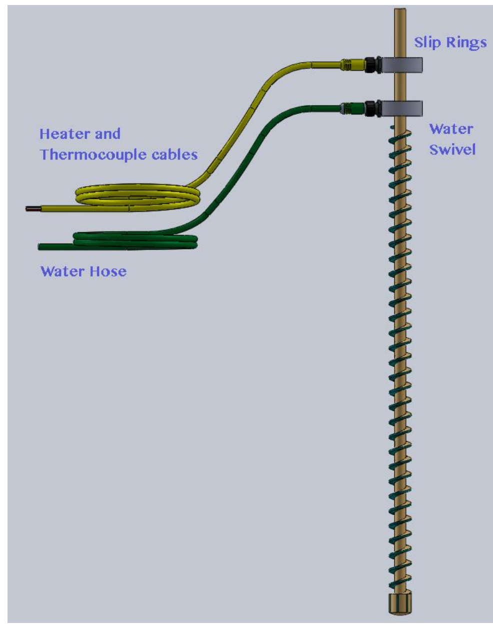


Figure 17: All-In-One Bit

11 Budget

The budget for the MIDAS project was projected to be $15,000. Funding was provided through generous sponsorship from the College of Engineering and Mineral Resources (CEMR), the Lane Department of Computer Science and Electrical Engineering (LCSEE), the Department of Petroleum and Natural Gas Engineering (PNGE), and the WV NASA Space Grant Consortium as well as the stipend received from NASA/NIA. With the NASA/NIA stipend covering about $11,200, the remaining expenses were taken care of by the other sponsors. The budget covers all costs associated with the fabrication and travel activities. The approximate division of funds is shown in Table 3. All fabrication expenditures were tracked by the faculty advisor and the team's Chief Financial Officer (CFO).

Table 2: MIDAS Budget

Category	*Estimated Expense ($)*
Equipment and Supplies	10,000
Travel and Hotel	3,625
Registration	1,375
Total Expenditure	**15,000**

12 References

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