Project: H.G. WELLS

Hidden Ground-Water Extraction Low Load System

A Mars Situated Automatic Ice Drilling System
Presented by: **The Colorado School of Mines**

Submitted to: NASA Revolutionary Aerospace Systems Concepts Academic Linkage
Theme: Design and build hardware that can extract water from simulated Martian subsurface ice

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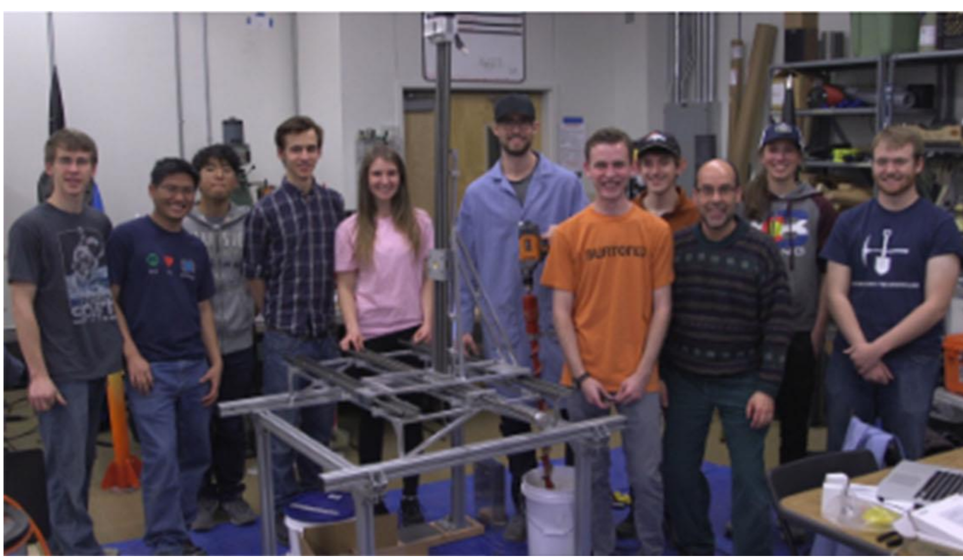
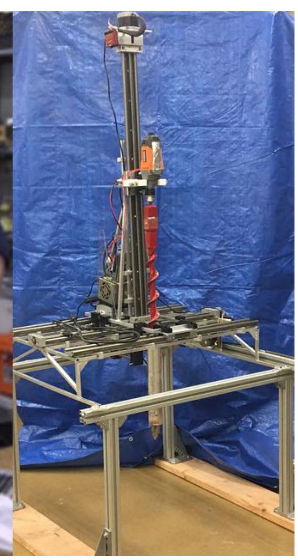

Introduction

This year's RASC-AL competition requires teams to design a drilling system capable of extracting water from the ice deposits below Mars' surface. Due to the combination of low atmospheric pressures and temperatures on Mars, water is not typically stable as a liquid which eliminates the possibility of liquid cuttings removal systems. Because of this, and other drilling phenomena anticipated on Mars, the Colorado School of Mines has developed a dry cuttings removal auger system that is capable of extracting water from subsurface deposits. Outlined in this report is the system description, technical specifications, design improvements, challenges faced, strategy for drilling, and the path-to-flight changes necessary for Mars application.

System Description

Mounting System

The chassis and vertical weldment used to support the drill were fabricated from 6061-T6 aluminum hollow square stock. This system was designed in SolidWorks and was subjected to finite element analysis to meet the required structural requirements and not exceed 4 kg in weight. A factor of safety of five was assigned to the model when subjected to maximum known dynamic load of the system. This accounted for the uncertainty of the stress concentrations at welded joints and unknown torsional load created by the drill when running. Once the design was finalized it was constructed using half inch hollow square 6061-T6 aluminum stock and welded together using a TIG welder. Problems were initially encountered with weld quality due to the thin hollow square stock thickness of 0.06 inches, but these issues were resolved with additional practice. The chassis and vertical weldment were welded together after initial quality-control issues were solved.

After completion of the structural weldments of the drill structure, the process of manufacturing brackets to attach the selected linear actuators to the drill structure began. To simplify the structure and prevent stress concentrations due to holes in the weldments, the brackets used to attach the actuators were machined out of 6061-T6 aluminum. This choice in material allowed them to be welded to the chassis and vertical weldment. Other structural fixtures that were not directly fastened to the two weldments were made from HDPE for easy manufacturing. Finally, Delrin brackets to mate the vertical weldment to the chassis were welded and manufactured. The ice collection box and its associated brackets for attachment to the chassis were welded and manufactured. Following this, all actuation motors were attached to the chassis and the horizontal rails were permanently attached along with their holding brackets.

System Excavation Operations

The system excavation operations consists of two phases. In the first phase, the auger and casing drill to the depth of the ice. The auger descends immediately following the bit. The rotational energy is provided to the casing from the auger by means of a rotational locking pin. Once the bit reaches the surface of the ice, it will continue to drill 3 inches into the ice so the casing can be set on the surface of the ice. The casing is set by disconnecting the pin. The system communicates casing set-depth by total vertical actuation and a WOB spike. As the drill continues and penetrates the ice, the ice cuttings ascend the auger and is caught either on the auger flutes or at the top of the casing by a funnel. Once the desired depth has been reached, phase 2 initiates. In phase 2 the drill translates vertically out of the ice and catches the casing with the pin. Once the drill and casing are above the surface, a collection box translates beneath the auger to collect the stored ice from the auger flutes and funnel. This is accomplished by reverse drilling the auger. Once the ice is captured in the collection box, the collection box retreats into its closed position and begins heating the ice. Once melted, the water is retrieved with a pump system downstream. The drill derrick then translates horizontally to repeat the process.

Water Extraction Filtration and Collection System

The water collection box is welded from aluminum. It is a rectangular shape with drainage channels engraved with CNC. Attached to the bottom of the collection box are conduction heating pads which penetrate the box with heat to melt the ice cuttings. Extending upwards from the base of the collection box is a series of fins which attempts to increase the surface area contact between cuttings and the hot metal. Downstream of the drainage channel is tubing and finally a positive displacement pump for water suction. Finally, fine mesh filter made from almond milk bags is strung from the base of the fins to the end of the box at a 20 degree vertical slope to filter debris. Figure 4 in the appendix shows the water collection system.

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, one that translates the drill horizontally, one that translates the auger vertically to penetrate the test bed, and one that actuates the heating box. The three motors are all controlled by a pulse width modulation output to control frequency and duty cycle during operation and a digital out to control the direction of rotation.

In addition to the stepper motors, the drill motor enables the auger to spin. The motor is an off-the-wall hand drill, which has been hacked to enable its control with LabVIEW. It is powered by a wall outlet, and by use of a transformer. The current-controlling board is powered with 24V. The output of the current controller is what feeds into a non-zero crossing solid state relay, which controls the speed of the motor. A general relay is used to control the direction the motor is spinning. The motor control occurs through a digital out to turn the general relay on or off, and a digital voltage control to manipulate how much power the motor is receiving, and thus how fast the drill spins.

A rectangular load cell was placed between the vertical actuator and auger to provide WOB during drilling. The load cell requires an amplifier to boost the output signal. The data is collected from the sensor through analog input voltage from the amplifier. Preceding the purchase of the auger motor, an s-shaped load cell was used to record torque while drilling through ice and the test bed-specific soil. Torque was also recorded and compared against by using a standard outlet Watt-meter. These values were used to purchase the correct size of auger motor. To record revolutions per minute (rpm), a unipolar hall effect sensor is located near the top of the drill. This location enables it to provide, through a digital input, accurate data reflecting the speed at which the drill is spinning.

Located on the heating box are four 26 Volt, 10 Watts/in^2 DC heating pads that provide the necessary temperatures to successfully melt the recovered ice. The heating pads are powered with a 24 Volt DC power supply and are controlled through a PID (Proportional Integral

Derivative) system, which takes measurements of current temperature from a temperature sensor and, by use of a relay, changes the amount of power the heaters are using to reach a desired temperature previously set by the user. Once the measured temperature reaches the desired temperature, the heaters only output the voltage necessary to maintain that temperature until the user alters it again. The temperature sensor previously mentioned is located equidistant from the four heaters on the bottom of the heating box. By use of an analog input, it provides accurate temperature readings of the entire heating system. These readings, as described, are what trigger the PID system.

The myRIO, 24V and 48V power supplies, relays, and the loadcell amplifier are all located behind the vertical support for the auger. They are contained by an acrylic enclosure that protects the components from ice and debris from the test bed. The wiring from all the sensors as well as the motor controllers is fed into the enclosure, and the wall plugs are fed out to a power strip which will be located on the testing desk where the computer control will reside. This positioning will enable easy access to the off switch of the power strip, which will be used in case of any emergency. Figure 5 in the appendix shows the MyRio circuitry.

Stuck Drill Prevention

Augers with a relatively large stem diameter, and therefore a relatively small flute surface area, decrease the distance necessary for the debris to travel outwards to the casing wall which assists in the cuttings removal efficiency. Although this is beneficial for cuttings removal, this type of auger geometry increases the chance of getting stuck in hole. As ice cuttings ascend the hole, they typically decrease in temperature. Depending on the pressure and temperature conditions, previously melted ice can re-freeze during its ascension up the auger flutes which can lock the drill string as a result. This problem is especially prevalent in large stem-to-flute O.D. auger ratio geometries because the liquid water has a higher aerial sweep displacement as it wedges vertically and horizontally between the stem, flute and hole wall. As the water spreads and potentially freezes against the surface of the bore wall, there is an increased contact area of bonded ice in comparison to other auger geometries. In contrast, a smaller stem-to-flute O.D. auger ratio, as seen in the H.G.W.E.L.L.S design, allows for the liquid water to spread horizontally across the larger flute surface which decreases the aerial contact between potentially frozen water and bore-wall. In addition to the design geometry discussed here, cuttings removal time, as a function of rpm will purposely fluctuate during the competition to decrease the time of cutting throughput to avoid stuck pipe conditions.

Technical Specifications

Table 1 lists the technical specifications of the Earth prototype.

Mass (Kg)	**Volume** (m^3)	**Length of Drill String** (m)	**Length of Drill Bit** (m)	**Rated Load** (N)		**Max Drilling Speed** (RPM)	**Torque** (N*cm)				**On-board Computer System**	**Communications Interface**	**Software**	**Power** (Volts)
				Chassis	**Vertical Weldment**		Drill Motor	Vertical Stepper	Horizontal Stepper	Ice Box Stepper				
48.2	0.79	0.72	0.076	700	200	600	10,100	280	280	88.2	Mac	MyRio	National Instuments	15, 24, 48

Table 1: Earth system prototype technical specifications

Design Changes and Improvements

As mentioned in the mid-project report, the initial project design planned for a single auger with two different outside diameters (O.D.). The bottom half of the auger was planned to have a wider diameter than the top half of the auger. This was proposed so that the casing could wrap around the smaller diameter section and descend into an open hole already cut by the larger diameter section of the auger. Testing this design concluded that this was not practical and secondary methods of setting the casing were considered.

Although several methods for setting the casing were proposed, each of them required an additional surface subsystem which would result in a net system weight of more than 50 kg. Due to this unforeseen design change and inability to reduce the weight of other sub-systems, the casing translates and rotates with the auger by connection of a pin. Although the casing rotation assists the drilling behavior of the casing into the subsurface, it also decreases the efficiency of cuttings removal as the cuttings attempt to ascend and descend inside the casing walls.

The casing is 17 inches long which provides a flow conduit through the overburden, meanwhile accounting for the non-uniform structural top of the clay because of depositional mounds created during previous drilling operations. A funnel has been attached to the top of the casing because the auger flutes run longer than the casing which could ascend the ice cuttings above the casing wall during the initial penetration of the ice.

It is important to note that these changes only affect the Earth design because the Mars concept does not require a casing set in the subsurface. Thus, the casing issues we've experienced do not disprove the validity of the Mars design. This being said, the Mars version must still be capable of lifting the cuttings up to 1 meter inside the casing. We have therefore still tested and proved the auger's ability to ascend cuttings in a longer casing. As expected, this required additional torque and rpm, but the values did not differentiate significantly.

Challenges

As initially anticipated, the auger and casing dimensions do not allow for a 1 inch solid to travel through the flutes. If the auger collects a solid of greater diameter than 0.55 inches, the solid locks up against the casing which ceases the motor's ability to rotate the auger. Because the constraints of the competition forced our team to use a size of auger that would eradicate the possibility of a flute volume capable of handling 1 inch solids, several programming strategies have been tested to handle this problem. The best method to date involved reverse drilling immediately following the stuck pipe. This is executed with a high rpm (~600 rpm) so that the solid is not only removed, but done so in a manner that thrusts it into tangential soil away from the drilling path. Testing with a lower rpm was not as successful.

Due to the last-minute changes to the casing subsystem, the prototype cannot control the casing's rotation during deposition. This is disadvantageous due to the following phenomenon: As debris collects on the auger flutes, the rotation of the auger creates tangential acceleration which forces the debris outwards toward the inner casing wall. If the casing is not rotating, there is a chance that the debris will deflect vertically in relationship to the stationary casing wall. Due to the helical structure of the auger, the debris is caught at a higher altitude due to the rotation of the flute surface. This phenomenon repeats itself, but opposite in direction during reverse drilling. If the casing rotates however, the tangential friction between the debris and inner casing wall is reduced due to similar directional velocities. This reduces the impact randomness and therefore also the chance of the debris elevating or descending as consequence.

Due to manufacturing errors in the auger connection joint and also the non-uniform weight distribution through the drill string, the auger encounters bit whirl as it rotates. This is especially prevalent at low rpm (~ 20 – 60 rpm). This is problematic because bit whirl decreases cuttings removal which can add up to 80% of heat generation during drilling operations (Uhlmann et al., 2003). In addition to heat generation, bit whirl also forces the stem of the auger to rotate outside of its plane of rotation thus drilling a hole that is wider in diameter than the O.D. of the drill bit. This creates additional spacing between the outer auger flutes and consolidated ice wall. Because of this, there is an increased chance that the ice will fall through this spacing as it attempts to ascend the auger. Testing suggested this was less of an issue at deeper depths where the temperature was cooler which maintained the consolidate structure of ice cuttings therefore reducing the slippage of ice through the flute-casing spacing.

Competition Strategy

During the first day, a circular pin attached to the auger will be inserted and removed through the casing as a means of rotating the casing during overburden drilling. During the second day, a second casing will be used that has a “t shaped” cutout. The pin will be placed in the t shaped cutout, which, when rotated clockwise will catch and spin the casing with the auger. Once the casing is set on the top of the ice, the auger will be reverse drilled until the pin is located in the middle of the t shape, allowing the auger to disconnect from the casing during its penetration into the ice.

Testing was performed to correlate rpm, WOB, depth and bit temperature with intentions of graphing operational parameters that could outline water melting conditions at the bit. This graph will be used as a guide during the competition to avoid melting conditions. It was hypothesized that a faster rpm would result in high bit temperatures. According to the results however, this was not the case. It is hypothesized that a higher rpm removes the cuttings from the bit location faster resulting in a shorter contact time between the ice cuttings and bit. Although a faster rpm ascends the cuttings more efficiently, it is not necessarily better since once the ice cuttings rise to the top of the auger and into the cone, they are in warmer atmospheric temperatures and therefore more likely to melt preceding their deposition into the collection box.

Integration and Operational Test Plan

Initial testing of the auger consisted of an AC hand drill, watt-meter, s-shaped load cell, hall effect sensor, and bathroom scale. The bathroom scale was positioned under the testing material to monitor differential weights and therefore WOB. The purpose of this testing was to confirm that the auger/bit combination could penetrate soil and ice given the competition constraints, and to record data for proper motor sizing. The s-shaped load cell was connected with a string, horizontally, from an anchor point to the hand drill. The average and max force values were recorded. Torque was then calculated by relating the force values with the load cell connection point (lever-arm).

Testing was performed to identify the rpm necessary to lift the cuttings in the casing. This value was approximately the same for ice and soil - 145 rpm. This was close to the anticipated value found with equation 1 listed in the path-to-flight section of this paper. A transparent plastic casing was used so that the team could observe the phenomena inside the tubing. The finalized casing for the system is made from Aluminum. The model of pipe was manufactured to a desired inner diameter and O.D. to provide a tight fit between the inner casing wall and outer auger flute edges. Although the different casings used for testing have different surface properties, the results are similar enough so that conclusions from both tests are considered relevant.

Energetics testing was conducted with water-damped soil, the results are illustrated in figure 1.

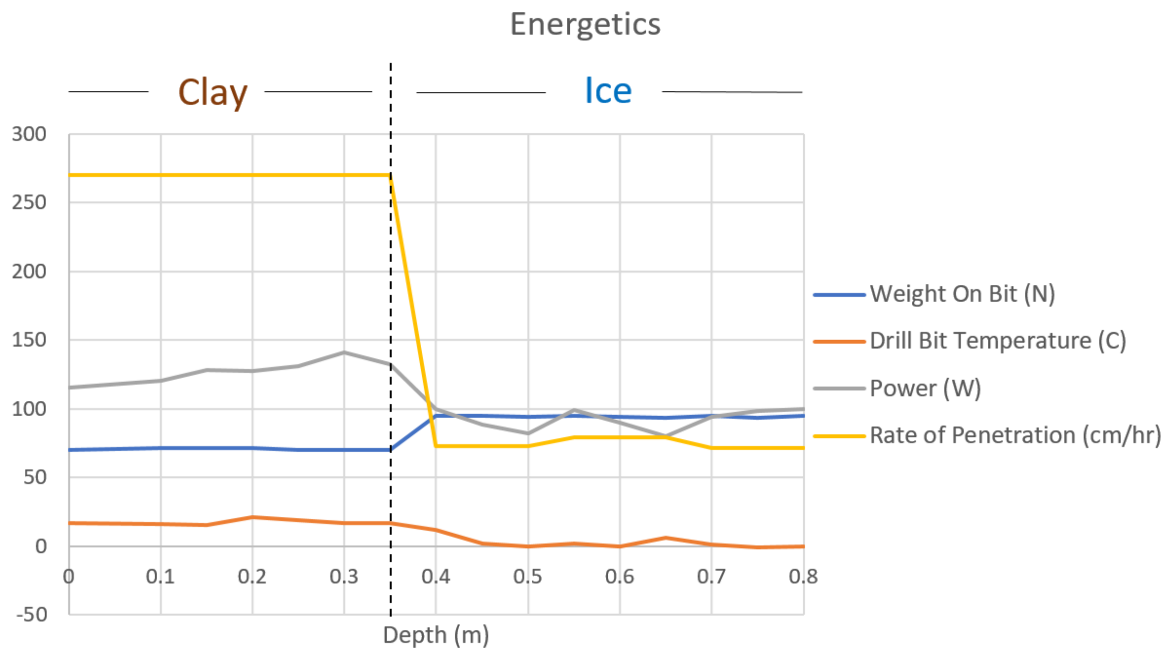

Figure 1: Energetics testing performed by translating the auger through ~ 0.35 m of Turface Professional Mound Clay and 0.5 m of frozen water

Recent testing has shown that we will be drilling much slower than initially communicated in the mid-project report. This is due to an incorrect math function that was previously programmed into the load cell. Because of this, initial testing was performed with more than 100 N WOB which results in a faster rate of penetration (ROP).

Tactical Plan for Contingencies

The system total current must not exceed 10 amps during the competition. The auger motor draws the most current, for which there are two drilling power dependent stages. The first stage includes the crushing and shearing phenomena necessary to segregate the formation into retrievable debris. The second stage is the extraction of the cuttings from the hole. The power consumption for the first stage of auger operations does not change significantly during penetration. The power during second stage however increases with depth due to an increase in auger throughput and therefore weight and frictional forces. Because of this, current must be closely monitored during the competition to assure the limit is not exceeded. Exceeding 10 amps was not an issue in testing.

Project Timeline

Figure 2 outlines the tasks, duration, start and finish dates of the RASCAL project.

Task #	Task Name	Duration	Start	Finish
1	Initial Design Phase	17 days	10/26/16	11/17/16
2	Writing of Project Plan	17 days	10/26/16	11/17/16
3	3D Modeling of Initial Design	10 days	11/4/16	11/17/16
4	Adjustments and Modifications to Initial Design	11 days	11/18/16	12/2/16
5	Procure Necessary Materials	129 days	1/6/17	5/15/17
6	Machine and Weld Chassis	16 days	1/31/17	2/21/17
7	Program Actuation Stepper Motors	5 days	2/3/17	2/7/17
8	Machine and Weld Vertical Support	17 days	2/5/17	2/21/17
9	Machine Heating Box Parts	21 days	2/8/17	2/28/17
10	Manufacture Connection Brackets for Chassis and Vertical Support	11 days	3/1/17	3/11/17
11	Program Load Cell	12 days	3/2/17	3/13/17
12	Testing of Manufactured Parts	5 days	3/10/17	3/14/17
13	Program Hall Effect Sensor	5 days	3/13/17	3/17/17
14	Preliminary Assembly and Testing	4 days	3/17/17	3/20/17
15	Mid-Project Review Report and Video	15 days	3/13/17	3/31/17
16	Manufacture Horizontal Actuation Motor Bracket	3 days	4/1/17	4/3/17
17	Manufacture Brackets for Heating Box	4 days	4/3/17	4/6/17
18	Weld Heating Box Parts	4 days	4/4/17	4/7/17
19	Disassembly, Hacking, and Programming of AC Hand Drill	21 days	4/5/17	4/25/17
20	Program Heating Strips	2 days	4/7/17	4/8/17
21	Program Temperature Sensor	2 days	4/10/17	4/11/17
22	Testing of Overall Programming	5 days	4/10/17	4/14/17
23	Attach Horizontal Actuation Motor	1 day	4/11/17	4/11/17
24	Integration of Heating Strips and Temperature Sensor Programming	4 days	4/12/17	4/15/17
25	Integration of Vertical Actuation Motor and Load Cell Programming	3 days	4/17/17	4/19/17
26	Finalize Travel Plans to Competition	1 day	4/20/17	4/20/17
27	Install Heating Box Filter	1 day	4/21/17	4/21/17
28	Install Heating Strips and Temperature Sensor on Heating Box	2 days	4/23/17	4/24/17
29	Install Heating Box Actuation Motor	3 days	4/28/17	4/30/17
30	Install Heating Box on Overall System	1 day	5/4/17	5/4/17
31	Preliminary Testing of Overall Mechanism	10 days	5/5/17	5/14/17
32	Machining of Electrical Case	10 days	5/9/17	5/18/17
33	Ordering/Organizing of Spare Parts	31 days	5/10/17	6/10/17
34	Final Wiring of all Electronics	14 days	5/10/17	5/23/17
35	Final Report	10 days	5/20/17	5/30/17
36	Final Testing of Mechanism	7 days	6/1/17	6/7/17

Figure 2: Schedule

Safety Plan

The system does not contain any hazardous chemicals. To mitigate electrical hazards, proper handling and grounding procedures will be followed. Emergency shutdowns will be installed where necessary Depending on future testing, safety guards could be installed around moving parts. Additional temperature sensors can also be implemented if the existing motors tend to heat up during longer testing intervals. The AC motor that spins the auger does not exceed 85 F during extended periods of drilling. This is due to the built-in fan.

Path-to-flight

Lower atmospheric pressure on Mars serves as the greatest influence for changes between the Earth and Mars design. Both systems utilize an auger system that elevates cuttings, however, rather than melting the ice and filtering it as a liquid, the Mars design heats the overburden/ice mixture with intentions of sublimating the water into a vapor. The vapor is then collected on cool surfaces which causes the water to condense back into a solid. Because the Earth design does not sublimate the water as a method of separation, collecting overburden is avoided which greatly complicates the drilling procedure. Due to separation by sublimation on Mars however, the Mars design can extract whatever intercepts the bit path. This simplifies the casing subsystem because it is no longer necessary to set it in the subsurface, as seen in the Earth prototype. It also eliminates the force of the casing on the surface therefore allowing the auger bit to utilize additional WOB during its descent.

In phase 1, the casing is set on the surface as the auger begins to drill into the formation. Rather than providing WOB by means of vertical actuation, the Mars design uses a drawworks similar to that in the petroleum industry. This means that maximum WOB is a constant as a function of weight, plus increasing flute loading during drilling. Once the mixture of subsurface ice and debris reaches the deposition point in the casing, it is forced to exit the drill string. The mixture will then fall vertically into a cylindrically shaped, sealed container. This is done by an electrically actuated rotating valve placed on the casing. As the valve rotates open, a brush rotates into the path of the auger flutes which will help to deposit the cuttings from the drill string into the collection box. Once surface temperatures drop, the system enters phase 2 which utilizes a powered heating and passive cooling system to transfer the water from the collection box to the condensing area. During this procedure, a valve downstream of the collection box is opened which will allow the vapor to enter one of the chosen condensing cartridges. Immediately downstream of the actuating valve is a one-way check valve which permits the flow of water vapor subsequent to sublimation expansion. Once the water vapor passes through the check valve and into a cartridge, the lower cartridge pressure and temperature forces the water to condense inside the cartridge. Phase 3 deposits the dry cuttings by rotating open the collection box floor. The three phases are illustrated in figure 3 below.

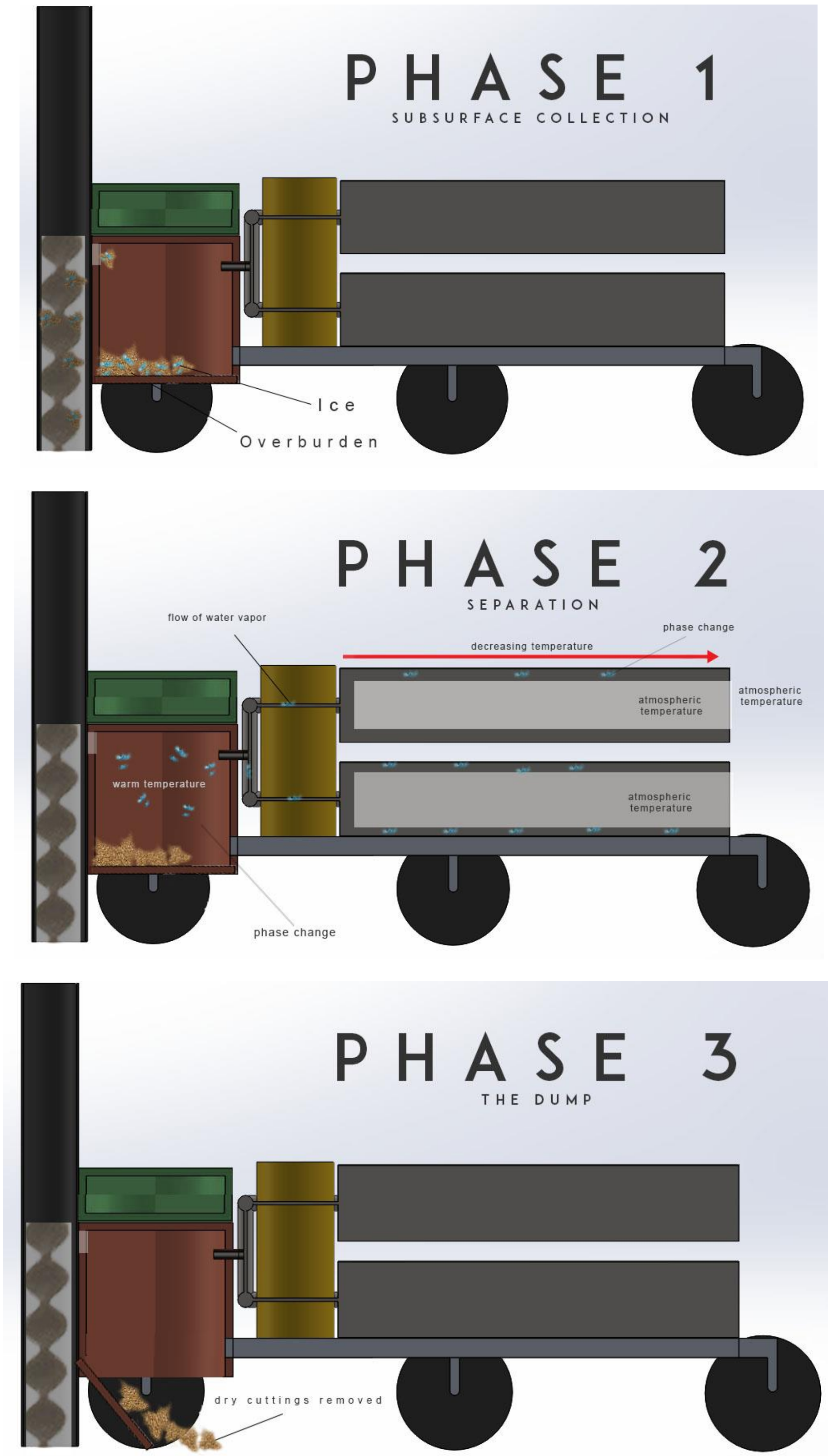

Figure 3: Phases 1, 2, and 3

The cartridges are cylindrical with a hollow inner, smaller in diameter cylinder which allows the cool atmospheric temperatures to contact the cartridge walls. A circular geometry also allows for a more uniform thermal gradient in contrast to rectangular geometries. The condensing area is composed of a 3 horizontal by 2 vertical, horizontally stacked, cartridge removal sleeve system. The cartridge removal sleeves should be manufactured from a material with a low thermal conductivity so that the cool atmospheric temperatures can penetrate the material thus increasing the likelihood of a phase change. The piping from the collection box to the condensing area must be short in length and heated to reduce the possibility of condensation preceding the water's entrance into the condensing area. This could freeze the valves or choke the flow of water vapor.

Similar to the proposed Mobile In-Situ Water Extractor (MISWE), two Advanced Stirling Radioisotope Generators (ASRG) will power the systems electronics. They are located between the collection box and the condensing area which allows for the generated heat to be recycled by the collection box, traveling lines, and cartridge entrance valves. The electric circuitry box will be positioned beside the ASRG's on top of the collection box which will recycle generated heat from both the collection box and ASRG's to keep the circuitry warm. It can be expected that the ASRG's will generate roughly less than 1 kW of heat. This is according to data provided from the 2011 MSL rover Radioisotope Thermoelectric Generator which is less efficient than the ASRG. It releases approximately 1 kW of heat (Zacny et al., 2012).

Sensors similar to the equipment used on the Rover Environment Monitoring Station should be used to forecast daytime temperatures which, if low enough, could permit daytime water condensation during drilling operations. Heating the collection box, in addition to drilling operations will increase the power requirements of the system. This may restrict the ROP due to a slower rpm as a function of lower available power. Figure 4 illustrates the various subsystems.

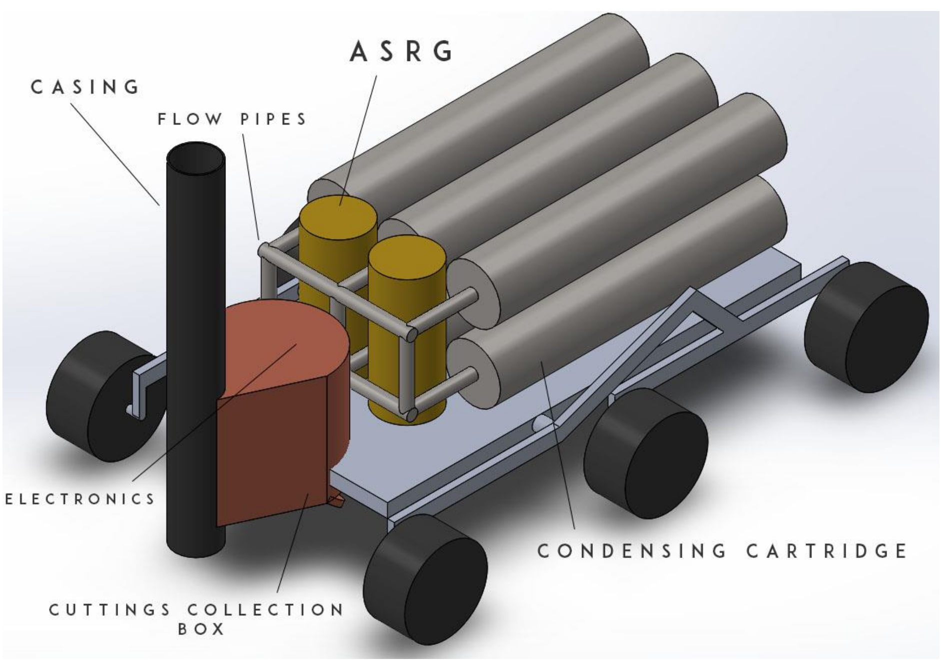

Figure 4: Path-to-flight concept

Due to the importance of reducing drilling power during operations on Mars, small auger diameters are often recommended. According to Kris Zacny and George Cooper, an auger diameter of less than 2 inches should be used when attempting to meet the conventional drilling constraints of operations on Mars. As mentioned earlier in this report, the H.G.W.E.L.L.S design consists of a relatively small stem diameter in comparison to the flue O.D. which reduces the chance of stuck pipe. This increased flute to casing volume allows larger conglomerates to traverse the flute path inside the casing. Assuming ROP is linearly related to bit diameter, and holding all other parameters constant, a larger bit diameter recovers the same volume of cuttings as a smaller bitt diameter in a unit time, minus the smaller bit system's necessity to pull out of hole more often. In addition to this, a larger diameter bit and therefore auger flute system results in faster tangential motion at the circumference of the flute which increases the efficiency of the auger cuttings removal system.

Because the auger flute pitch height is directly proportional to the pitch angle, a balance of the two is required to optimize the auger's ability to efficiently rise the cuttings. An optimal pitch angle of 20 degrees is recommended (Kris Zacney and George Cooper., 2005). According to equation 1 from *Methods for cuttings removal from holes drilled on Mars* by Kris Zacny and George Cooper, the scroll surface of the auger should have a low coefficient of friction. Nedox (Magnaplate) is an option. According to this recommendation, the Mars design should have a smaller pitch height angle than currently implemented on the Earth design.

$$N = \frac{30}{\pi}\sqrt{\frac{2g}{D}\frac{\tan(i)+\mu_s}{\mu_w}} \quad (1)$$

When designing a bit for Mars, it is important that the bit geometry is suitable for subsurface penetration with limited WOB and manufactured or coated with a wear-resistant material. Both a PDC and carbide bit have been proven to tackle these difficulties, however, PDC is preferred due to its advantage in self-sharpening and efficiency with increasing depth and also the plastic behavior of permafrost (Kris Zacny et al., 2007). Due to the low gravitational forces on Mars, comparatively to Earth, multiple, symmetrically placed thermal stable polycrystalline diamond compact cutters should be used (Duan Longchen et al., 2014). Test data presented at the 40th Lunar and Planetary Science Conference in 2009 also recommended a PDC bit rather than a carbide. The PDC bit should have a small, positive rake angle (Zacny, 2007).

The pressure temperature relationship that governs water phase behavior depends on the drills location on Mars. The recent Mars Odyssey neutron spectrometer data suggested that the top meter of Martian soil accommodates roughly 20% to 50% water by mass at 50° latitude, and up to 100% at the North pole (Feldman et al., 2003).

According to data provided by the Mars Orbiter Laser Altimeter, on the Mars Global Surveyor, the elevation in the southern hemisphere is significantly higher than in the northern hemisphere. Because of this, the atmospheric pressure in the southern hemisphere is low enough that surface conditions are generally below the triple point of water (Haberle et al., 2001). This means that water can exist in the liquid phase, though only for a small range of temperature and pressure conditions. This is not necessarily troublesome in phase 2 where the temperature of the collection box is regulated, although liquid water in the drill string during phase 1, because of increased auger temperatures during drilling, should be avoided. Not only does this increase the chance of stuck pipe due to liquid re-freezing, but also, water will not as easily ascend the auger when in the liquid phase.

Lower atmospheric pressures in the Southern hemisphere eliminates the possibility for water to exist as a liquid. In addition to this beneficial atmospheric condition, if bit temperatures cause the water to sublimate premature to its deposition in the collection box, the system will notice an increase in drilling efficiency. This is expected to double the ROP and half the power requirements of the drilling system (Kris Zacny and George Cooper 2004). Although this is mostly beneficial, it reduces bit life by increasing the bit wear (George Cooper, 2005).

Budget

In regards to budget, the team would first like to express its gratitude to the National Institute of Aerospace for the generous stipend provided for the competition. The money provided was enough to cover all costs associated with the competition without the need for outside funding. However, the team would like to thank IGUS and Chris Lang from Tacuna Systems for their contributions. The donations of 2 actuator rails from IGUS worth about $600 in total and a load cell worth about $400 from Tacuna Systems were greatly appreciated.

Item	Quantity	Total Cost ($)	Donations
Mechanical			**ESTIMATIONS**
0.5x0.5 hollow steel rod 6 ft	11	$158.82	
Sheet metal (aluminum) 6" by 6"	1	$65.96	
Multipurpose 6061 Aluminum, Rectangular Bar	1	$69.36	
Multipurpose 6061 Aluminum, Sheet	1	$79.69	
Delrin Sheet (12"x24"x1")	1	$167.11	
X direction actuator	1	$0.00	
Z direction actuator	1	$0.00	
Belts for actuators	1	5.82	
Actuator rails	2	$0.00	$600.00
Guide Rail	1	$187.45	
Auger (2-4 inch)	1	$248.85	
Carriage Threaded Hole	2	$39.32	
Steel Nylon-Insert Locknut	1	$6.51	
Hex Drive Screw	1	$22.30	
General Purpose Tap	1	$6.61	
Drill Bit	1	$3.53	
AmpFlow Electric Motor	1	$79.00	
0.5 in Spade Handle (Hand Drill)	2	$338.00	
Blue Tarp	1	$14.48	
Old Motors	2	$49.98	
Ceramic Disc Magnet	1	$11.39	
Stainless 304 Pipe Schedule	1	$44.30	
Heating Elements	4	$164.00	
PVC Piping (2"x10')	1	$8.56	
Aluminum Pipe	1	$45.16	
Filter	1	$15.28	
Teflon Spray	2	$22.69	
End Mill	1	$20.51	
Tungsten Electrode	1	$43.50	
Black-Oxide Head Screw M8	1	$10.00	
Black-Oxide Head Screw M6	1	$6.90	
General Shipping		$115.84	
Electrical/Computer			
Force Transducer/Load Cell	1	$0.00	$400.00
AC Micro Drive	1	$186.00	
Solid State Relay	1	$17.25	
Portable Cord 250ft	1	$133.00	
Instrumentation Cable 100ft	1	$85.00	
100ft 18 Gauge Wire	3	$32.85	
Thermocouple	1	$9.95	
Extech Test Lead Kit	1	$17.47	
Digital Multimeter	1	$49.99	

Solderless Breadboard	2	$19.38	
120pcs Ribbon Cables Kit	1	$9.98	
Hall Effect Sensors	11	$7.44	
DC Motor Driver	1	$23.49	
myRIO	1	$500.00	
Kill A Watt EZ Meter	1	$28.97	
Package of Resistors	1	$12.66	
Solder Iron (for trip to Virginia)	1	$32.99	
LabView	1	$19.99	
Temperature Sensors	4	$6.00	
Darlington Transistors	5	$4.50	
General Purpose Relays 15A	2	$41.92	
Heat Shrink Tubing (0.125in)	4	$24.08	
Heat Shrink Tubing (0.25in)	4	$21.28	
Heat Shrink Tubing (0.375in)	4	$35.76	
Headers & Wire Housing Headers	100	$11.40	
Board Mount Temperature Sensors	9	$12.60	
Board Mount Hall Effect Sensors	4	$3.76	
Wire Wrap or Protoboard Expansion	1	$9.99	
SSR Phase Angle Control Module	1	$89.74	
Transformer (Energy LMT)	2	$32.50	
Snubber Network	1	$49.82	
Current Transformer 1000T	2	$31.76	
General Shipping		$109.05	
Simulation Box			
Collection Box	1	$82.22	
Water Pump Filter	1	$4.49	
Heaters	7	$276.36	
Water Pump	1	$14.99	
Pitcher Mound Clay	1	$12.00	
Buckets (and lids) with Angular Gravel	1	$15.00	
Ice Shaver	1	$32.49	
General Shipping		$32.11	
Travel			
Flight		$2,410.00	
Transportation		$300.00	
Food		$300.00	
Lodging		$1,100.00	
Shipping		$200.00	
		$8,301.15	
		$11,200.00	
		$2,898.85	

Table 2: Earth prototype budget

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Appendix

Figure 5: Drilling system

Figure 6: Drill bit

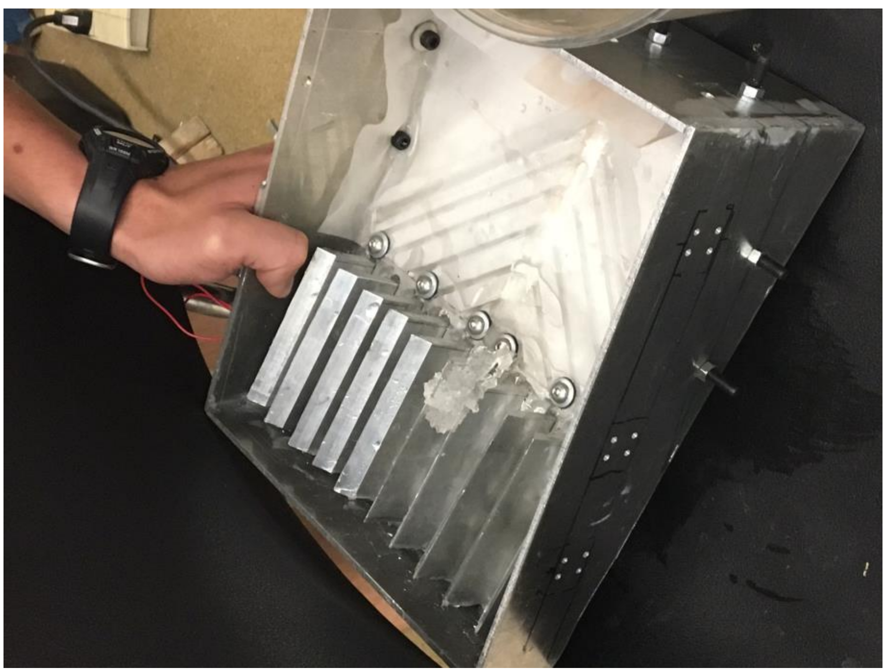

Figure 7 Melting box:

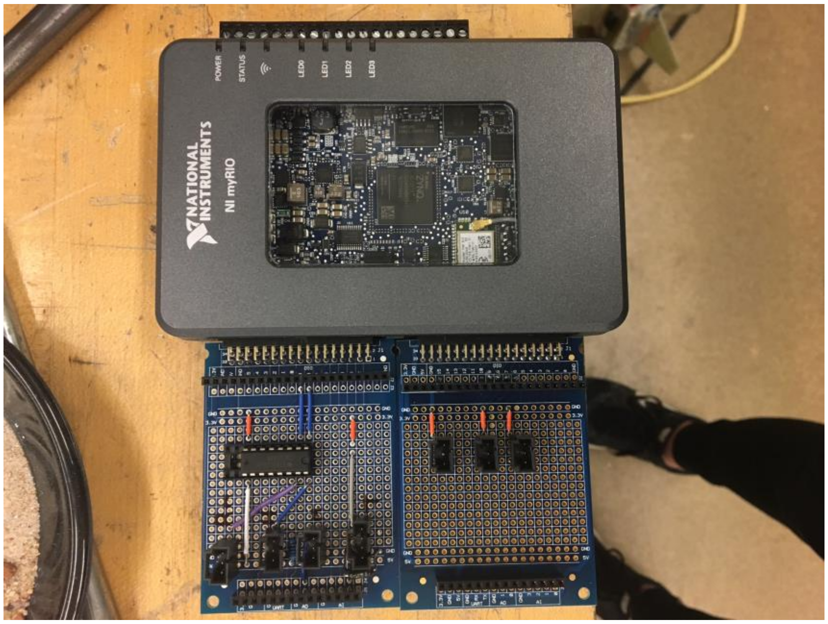

Figure 8: MyRio connection port