RASC-AL SPECIAL EDITION: MARS ICE CHALLENGE

2017 Team Post Competition Analysis

INDIVIDUAL TEAM POST-COMPETITION ANALYSIS IN RESPONSE TO THE FOLLOWING QUESTIONS:

- **Where did you fail and what did you learn from it?**
- **What changes would you make to improve your system next year - and why?**

Alfred University

While we were pleased with our progress given the several set-backs encountered during our time at Langley, we ended the competition approximately 2 inches short of reaching the ice layer. Our outer drill motor became disabled and as such we were limited to utilizing only the inner drill to approach the ice layer. This in turn exposed our inner drill shaft to the overburden and compromised the integrity of the heating coils. To prevent these issues from occurring again it the future, we would recommend making the following improvements to our system:

First, we determined the need to better utilize gear ratios would be paramount for the drilling process. Unfortunately, during the competition, one of our drill motors was worked to the point of failure. Had we created a mechanical advantage with gear ratios, we believe our motors would not have needed to be worked as hard to drill through the overburden, ultimately saving the motor as well as lowering the power consumption of the system.

Another issue that we encountered was the rapid degradation of select components. It was anticipated that certain parts would wear over time and counter measures were to deal with such issues. What was not anticipated was the speed at which certain components would reach the end of their usable lives. One measure to help abate these issues would be to conduct endurance testing to determine which components are best able to run for long durations of time, as opposed to the stop and start testing that we had initially conducted. From these tests, any necessary modifications to parts can be made to improve their longevity.

The biggest change that we would recommend to the system is the overall system process itself. While a multi-drill system is appealing on paper, it was found to be more cumbersome and a pain in practice for several reasons. The first reason was due to our manufacturing capabilities; the tolerances that were required to make this system function as was intended were not attainable with the equipment that we had. Had we been able to access more precise means of machining, such as with CNC machines, we believe the system would have worked closer to the modeled version. Second, the amount of energy required to extract a cylindrical volume of overburden with a multi-drill system ended up being greater than anticipated. This was a testing issue, as we had been testing with topsoil native to Western New York, as opposed the water saturated clay used at Langley. Our power system would need to be revamped to accommodate for this. Lastly, the materials that we chose could have been better optimized to suit the needs of the project, such as using composite vertical and horizontal supports the have improved strength and rigidity, while saving weight.

Our electrical system could have been more organized and systemized. We tried to optimize and minimize the system for efficiency, but experienced some heat issues.

Finally, we would recommend using a coring process as opposed to a multi-drill process to save on complexity, as well as weight, requiring approximately half of the materials used when compared to our original system.

Takeaways: Through this experience we learned that drilling on Mars will be no easy task. To better our design for the future, we would look to recruit a wider variety of engineers. Our team was comprised of fifteen mechanical engineering students, all with similar technical backgrounds. Having a variety of engineers is critical, especially during the design process as different disciplines bring both varying expertise based on their specialization, as well as a different perspective on design. Additionally, we found that the feedback given to us from other types of engineers during the competition proved to be incredibly helpful and allowed us to see things that had previously gone unobserved. Our greatest takeaway from the competition though was learning just how critical the testing phase is, and how thorough it needs to be in order to reach a finished product. When we organized our testing, it was conducted systemically to test each of our systems individually, and every time each system worked seamlessly without flaw. However, prior to the competition, multiple systems tests had not been conducted, and that is when we found several flaws with our system. Ultimately a variety of tests, as well as pushing the system through more rigorous testing would have helped immensely with the competition.

Colorado School of Mines

We segregated the team into subsystem groups. This was helpful in terms of subsystem “deliverable” accountability, but the groups became too focused on their individual tasks and sometimes forgot to see the big picture. This resulted in work that often created problems for other subsystem groups. Looking back, we should have stressed more cross-subsystem group communication, early and often.

We also spent too much time anticipating results with pen and paper rather than buying the tools and testing our assumptions. We learned to test early and often.

There were a couple of test parameters that we misunderstood heading into the competition. This was our fault. Most significant, was an increase in distance from our platform to the ice surface top. This reduced the length our drill could reach, and therefore the ice we could collect per hole. This forced us to change our strategy from fewer deep holes, to more shallow holes which resulted in additional non-productive casing setting time. The purpose of the casing was to provide a medium for which the cuttings could ascend the auger flutes while also segregating them from the overburden lying above the ice. However, overnight NASA surrounded the ice beds with "dry ice" which dropped the clay temperature lower than we were expecting. This resulted in a harder to penetrate material which significantly slowed our casing setting times.

Next year, we would try to bring an additional computer science and electrical engineering student onto the project. The electrical/computer science interfacing was unquestionably our biggest challenge. This being said, not having students in these areas forced the rest of us to spend time learning these disciplines. When we started, we were struggling to turn on an LCD. It's empowering to realize that in the end we created a robot that could drill autonomously for 12 hours.

Having to purchase expensive materials really forced us to understand what it was we were buying. It was truly an authentic form of education, one that is difficult to experience in "textbook academics".

Next year, we would decrease the diameter of our bit. Both testing and Mechanical Specific Energy data suggested a 2 inch bit was too big. The increased "bit face" required more energy to penetrate the ice and the increase in hole volume did not pay off. We would also change the angle and material of our auger flutes. They were not optimized for lifting cuttings (we found this out too late in the design process).

North Carolina University

Design improvements:

Motor Cooling & Torque: A motor should be selected with sufficient torque for the bladed auger selected, for the 4 inch auger used more than 300 in-lb is needed if the overburden is near liquid/mud conditions. The ice & overburden must be at design temperature (-0 - -40C) during all stages of extraction for proper functioning of a bladed-shrouded-auger design as friction with the sidewalls can cause overheating. Less torque would be needed if there is less friction between overburden and shroud walls.

The mission-ready motor must be suited for sustained loads without overheating, single body aluminum construction with phase exchange heat pipes is recommended, and additive aluminum manufacturing methods would be very useful.

Screw drive would be better for positioning than belt drive if 3 axis positing is desired, weight would be a consideration.

Competition wise, a simpler design (1 axis) may have worked better, but for flight ready hardware we still think 3 axis control would be a huge advantage to serviceability (less frequent trips to drill site to move the drill).

Future designs should make use of as many tension structures as possible using guy wires, they provide dampening against vibration modes as well as adding stiffness when operating at maximum height.

A single body construction, consisting of the fluted auger, pilot bit, and auger blades, would be recommended to achieve a custom flute separation distance.

Custom, single body construction of the force-on-bit to auger mount would provide more reliable force on bit construction.

University of Pennsylvania

Our system consisted of several subsystems that were tested separately in order to ensure that they could operate effectively. However, our team had significant challenges with system integrations because although each subcomponent was meticulously designed and prototyped, we did not leave ourselves enough time to bring all the pieces together and test as an integrated system. We learned to not underestimate the complexity of or the amount of time required for final system integration.

Additionally, our drill motor stalled many times while excavating through the overburden during the competition. We were only able to find a limited number of equations related to drilling through clay or ice. Because of this, we were unable to accurately calculate the required torque and power for our drill with much certainty. We learned to rely on experimental information more heavily when theoretical information is limited.

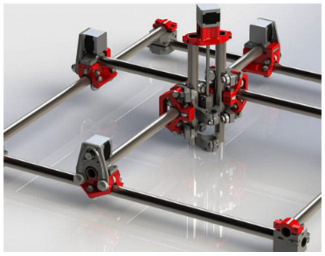
If we were to redesign our system for next year, we would stick with our actuated core drill design, but we would focus on reducing overall weight and increasing the rigidity of the actuation system. In order to reduce weight, we would use a smaller diameter core drill. A smaller drill not only removes weight from the drill itself, but also removes weight from the actuation system needed to move it. We originally chose a large diameter drill because we thought the rate of penetration of the drill would be quite low and we wanted to maximize the amount of ice we obtained from each hole. However, rate of penetration ended up being higher than we predicted, thus reducing the need for a large diameter core drill. To further reduce weight, we would likely attempt to design a melting system that could melt the ice within the drill. This would remove the need for the melting chamber, thus reducing the weight and complexity of our overall system.

The other main focus would be improving the rigidity of the core drill actuation system. Our system experienced significant oscillations when the drill was powered on; this greatly decreased the positional accuracy of the drill. Additionally, our system was beginning to shake itself apart by the end of the competition. We believe the fundamental actuation concepts (lead screws for X and Y axes and Rigibelt for Z axis) have the potential to work, but much more secure guide carriages are needed for the rails. Ideally, we would use a guide carriage that completely wraps around the guide rail. We believe roller coasters would be a good source of inspiration for this.

University of Tennessee, Knoxville

The biggest problem with our device was our trencher. As such, most improvements would focus on making the trencher effective. As we have probably mentioned already, our team had next to no robotics experience entering the first phases of design. Now that the team is more experienced, the time and money spent solving relatively fundamental problems last year can be leveraged into a much more thorough design phase for potentially problematic elements, like the trencher.

The chassis from 2017 model of our device placed the attachment of each tool head at the highest point in the possible working space. This caused the trencher to produce a significant moment on the linear actuator to which it was attached. The first and most fundamental change would be to change the frame so that XY translation was handled as close to the test bed as possible, similar to how a modern CNC machine works. The image below demonstrates what I mean, with the horizon plane of the chassis as low to the test bed as possible. ***(Image credit to ASME)***



This would significantly shorten the moment arm the trencher applied to the chassis, making it much easier to implement a two-point attachment system for the trencher, so that the linear actuator doesn't bear the shear caused by the trenching moment. This would allow us to re-design the trencher to make it more robust when dealing with compacted or wet overburden. Most industrial scale trenchers (used for strip mining) use very low profile cutting teeth to grind through soil and rock, and account for the lower volume extraction per revolution by spinning very quickly. These units are also typically cylindrical instead of oblong, reducing their weight. The lighter, more robust chassis and reduction in weight spent on trencher size would allow us to implement a more robust trencher with a larger, high-torque motor (with a gearbox) and steel or ceramic-tipped teeth instead of buckets, to prevent wear. Overall, this type of trencher, like the industrial trenchers by which it was inspired, would be suited to dig through both cohesive (wet) and hard-packed (frozen) overburden. Other improvements, such as procuring shorter linear actuators, redesigning the filtration system to prevent overflow, and re-organizing wiring, would also be made to "clean up" the design.

Takeaways: Members of our team learned technical skills like CAD, Python, 3D printing, and Machining. Our programming and electronics team had to learn all the skills required to wire and control the robot from an external laptop. Our team had to learn how to design drive systems and components based on available parts. The competition was also an opportunity for team members to build technical writing skills, time management skills, in some cases leaderships skills. Members of the team also had to learn how to mathematically develop a model for a system, identify the limits and assumptions of that model based on applied boundary conditions, and defend those choices with evidence from relevant scientific literature. Team members also learned how to use computational methods to analyze systems, both in the aforementioned models and physical systems on the prototype. Members also built organization, communication, and financial management skills.

Additionally, our team gained practical robotics knowledge. For instance, our team learned basic things like the different types of shaft collars and the advantages and disadvantages of each. Our team learned, broadly speaking, what parts are commercially available and which must be custom made, and how modify commercially available components and minimize machining to construct parts which would otherwise be prohibitively expensive. Our team learned what can and can't be done on the different hardware available to us through the university, and what level of precision can be expected from each, as well as learning what level of precision is required for different components. Our team also learned the importance of, and techniques to design for maintainability and ease of repair.

Specific to problems that arose at the competition, our team gained insight into planning for a competition setting. Our team is now much more aware of the types of failures that typically happen during long demonstrations and can design around those issues (overheating, wear on motors and electronics, etc.) Our team also now understands the importance of "over-engineering" critical design elements so that they still function correctly in sub-optimal or unexpected operating conditions.

University of Texas, Austin

One thing in particular we learned about is the importance of testing. During our rig tests, we burned out all three of our heating coils and so we had to scramble before the competition for a solution. If we had tested sooner we would have had an easier time dealing with this problem.

Based on the results of this year's competition, here are a few things we would change about our system:

- Use a coated heating coil rather than uncoated for superior durability
- Spade type bit design instead of the wood cutting bit type we used
- Bars on the bit to prevent mud from collecting around the casing.
- Add a bottom hole temperature sensor to ensure the casing doesn't get too hot when heating.

Additionally, we would consider removal of the outer casing. Our design utilized an outer casing to prevent collapse of the wellbore, but this year's test bed was firm enough to hold up without the casing. The removal of the casing will allow our team to shrink the size of the bit dramatically and increase the Rate Of Penetration, ROP.

When the casing is removed, the heater (which was previously located on the casing) will need to be rethought. Some of the NASA engineers mentioned that on the rovers on Mars are powered by nuclear reactors that don't easily produce electricity. They mentioned that a design which heated with a thermal fluid would be superior than a design that used an electric heater. As such, our thoughts are to go with a design that pumps a hit brine down the stem of the drill bit.

West Virginia University (The In-Situ Resource Extraction System, Advisor: Evans)

Lessons Learned:

- The drill bit's length beyond the auger stem should be minimized in order to facilitate the conveying of regolith cuttings up the drill stem.
- The drill needs to cut approximately 3 inches into the ice in order to minimize any excess contamination of the meltwater by regolith mud.

Points of Failure:

- A pump was incorrectly connected and was not identified until operations began. Additionally, two valves malfunctioned for no apparent reason.
- A second pump stopped working towards the end of the competition. The cause of this failure was not assessed. A higher quality pump would have most likely avoided the issue.
- In general, we did not take full advantage of our available amperage. We used only 2.5 of an allotted 10 A. Additionally, our self-assembled drill motor only operated as a rotary drill. As a result, we did not utilize our WOB as efficiently as we would have had a rotary percussive motor been used.

Improvements:

- A new rotary percussive drill motor will be selected that provides more cutting power to the bit and conveys regolith without stalling.
- An injection system that uses a hotter fluid will facilitate the extraction of far more water.
- The drill bit will be modified into a cutting strip of tungsten carbide welded to the bottom of the auger to facilitate conveying operations.
- As an alternative to the injection system, a single heat probe could be lowered into the borehole after it has been drilled and melt the ice. We could then extract the meltwater through a system similar to our current extraction system configuration.

West Virginia University (MIDAS, Advisor: Klinkhachorn) – Winning Team

First and foremost, we learned the overburden is much harder to deal with than we anticipated. We thought even though it was loosely packed, when it was chilled in the container with the dry ice, it may become relatively firm. We also thought since there was so much overburden, the weight of it all would probably pack the soil tightly but leave the crust somewhat crumbly. We discovered it was pretty loose overall and prone to collapsing. A weight on bit didn't even register when drilling through the testbed, except when we hit the ice. In the future we would use a deployable casing wall in unison with our drilling system to prevent major collapses.

Another lesson learned was the method of liquefying ice in the bore hole is much better when the heater assembly is used as a melting probe. By this we mean on day one we drilled to target depth and then deployed the heater in the ice. On day two we drilled to the ice layer and let the heater melt its way through as it was gradually translated down to target depth. The first method required very high heat because it utilized heat radiation to melt ice until water made contact with the heat sink, which was terribly inefficient. We also didn’t have a way to sense when there was water, so we did boil off some water with the high heat. The second method on day two utilized the principles of heating by conduction and convection, which melted a lot more ice and led to a very large overburden collapse. Obviously heating through conduction and convection is more efficient, but it was one of those things we didn’t think to try until we got there.

A lesson learned about the heating method itself was that we required a high wattage heater of shorter length. This would have prevented a lot of problems with overburden collapses. As the shorter heater melts its way down, it will eventually sink much farther below the ice-overburden interface. If most of the melting process is done further down, a cavity in the ice will form that will create a ceiling to hold the overburden. Also extracting water while melting down through would be beneficial to prevent continued melting of the ceiling while translating the heater downwards. A sensor for water level feedback would be great to integrate into the extraction assembly for the future.