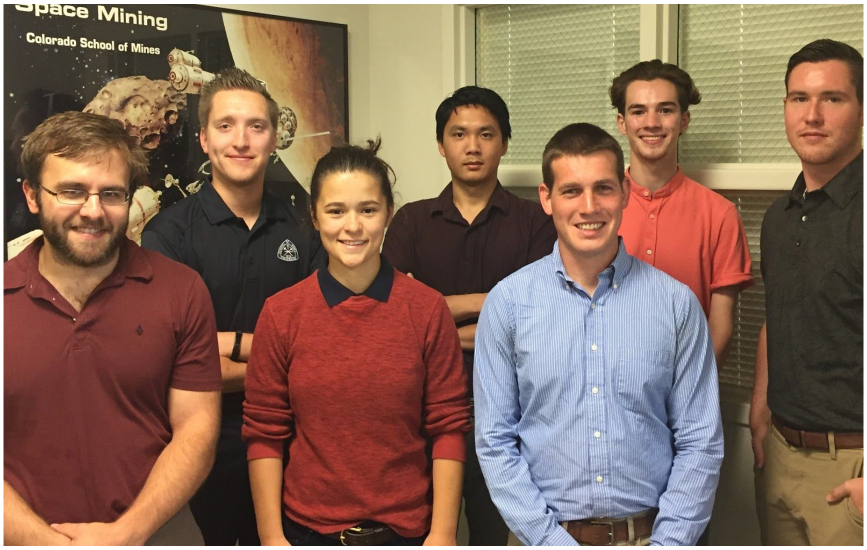
RASC-AL Special Edition: Moon to Mars Ice and Prospecting Challenge

May 2019 | Final Technical Report



Team F.I.R.E. Drill

(**F**luid and **I**ce **R**ecovery and **E**valuation Drill)

Team Members:

Nathan Vermeer	*Project Manager*
Branden Sage Neary	*Technical Lead*
Alexandra Garza	*Control Systems*
Samuel Kincaid	*Drilling Systems*
Deep Joshi	*Drilling Systems*
William Hayne	*Extraction and Filtration Systems*
Jacob Malkin	*Structural Systems*
Arvad Budijanto	*Structural Systems*

Faculty Advisors:

Dr. Angel Abbud-Madrid

David Dickson

Contents

1. Introduction

Team FIRE Drill (Fluid and Ice Recovery and Extraction) has been designed and optimized for melting and extracting the maximum amount of ice while simultaneously filtering out regolith fragments from the water. The NASA RASC-AL Moon to Mars Ice & Prospecting Challenge presented university teams with the opportunity to fabricate a prototype system that can drill through, extract, and filter water ice from a simulated Martian subsurface environment and deliver to a collection container. The secondary objective of the system is to develop digital coring methods that deliver information about the hardness, location, and thickness of each layer of overburden.

One goal of operation is to develop a new-fashioned design which incorporates a rotary percussion drill with a sleeve body to prevent any excavation from collapsing in on itself. This approach utilizes an articulated heat probe that will be lowered into the excavated hole to melt the ice. By stabilizing the borehole with a sleeve and using forced convection to inundate the subsurface ice body, the team expects to efficiently extract water while also being capable of characterizing the overburden layers with high accuracy. Integrative testing has given high expectations that the final design will operate efficiently, and quickly melt and extract ice. The following report details both the finalized design as well as the changes made from the previous design presented by Colorado School of Mines last year.

2. System Description

2.1. Water Extraction Capabilities

The use of a peristaltic pump will provide the capability to obtain water without the need to prime the system initially. The pump can also pull some debris through its tubing to minimize the amount of clogging which would occur with other types of pumps.

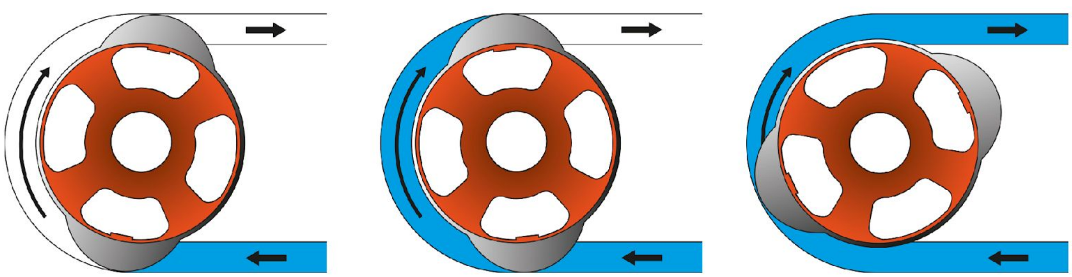


Figure 1: Peristaltic Pump

2.2. Digital Core Capabilities

Labview code will collect auger shaft RPM, torque transmitted through the auger shaft, depth of wellbore, and allows weight on bit (WOB) to be measured in real time while drilling. The data will then be exported to an LVM file and the data then imported into a Matlab program that will clean out the excessive noise from drilling. This noise is especially present in the torque sensor. After the data is cleaned the LVM file will be exported and imported into another Matlab code that will combine the data to create a graph of relative hardness versus distance traveled [1]. The amount of data points being collected necessitates that signal cleaning and mathematical formulation take place off of the myRIO and the control computer. With this approach the materials will be ranked from most to least hard, with an estimation of layer depth.

2.3. Sub-System Descriptions

2.3.1. Mounting System

The chassis of the drilling rig is constructed out of 6105-T5 T-slotted aluminum extrusions selected for its strength, lightweight and ability to disassemble. The base of the chassis consists of a 0.95 m square platform of 25x50 mm extrusions that will rest on top of the competition test station. Two sides of the chassis base will rest upon the provided wooden 2x4's while the other two sides span between the boards to support the main load of the drilling system. All four corners of the chassis base are bolted onto the 2x4's using 0.5 inch hex bolts and nuts, and the holes for these bolts are in a 0.9 m square from center to center. The bolts are inserted from the bottom of the 2x4's and hammered in so that the heads of the bolts lie flush with base of the boards. This mounting system is functioning and is currently supporting our chassis for drilling operations. The chassis is based off of last year's CSM team and is designed to fit the NASA test bed provided at the final competition.

2.3.2. Excavation System

Excavation will begin by drilling into the overburden at an optimal rate that allows quick penetration while ensuring the excavation core remains concentric. The auger is 36 inches in overall length and has a four piece tungsten carbide cutter head; allowing for deep operation through high strength regolith. During drilling operation a borehole casing with an attached hole saw will be lowered in conjunction. Once the desired depth is reached, which will be the depth where ice begins, drilling operations will cease. The drill will be reversed to unlock the hole case attachment mechanism. Next, the drill will be carefully extracted while the borehole casing is left behind. Basic sensors will give us primary feedback to determine the performance of the drill and overburden consistency. A load cell will give us our weight on bit (WOB) to give us preliminary information regarding rock hardness. A hall-effect sensor will give us RPM to measure overall remaining drill power. The string linear potentiometer will guide the vertical distance between surface and ice. Finally, a torque sensor has been welded in line and in between the drill and auger. Beyond outputting additional measurements, the torque sensor acts as an additional contact point to further stabilize the drilling process and ensure a near vertical borehole is achieved.

Figure 2(a): Spin-lock Bore Hole Casing

Figure 2(b): Replica of Excavation Auger

2.3.3. Water Extraction Systems/Technique

Water extraction begins immediately after the hole has been drilled. The drilling sleeve will remain in the soil after the hole is drilled and will prevent regolith from falling into the hole and entering the ice layer. The heat probe will then be inserted into the hole and placed on top of the solid ice layer.

The heat probe is made out of 3D printed aluminum. It is shaped to conduct heat into the water and ice most efficiently. It has fins both to conduct heat effectively to the water and to allow for a high convection heating mode. In this mode, the heat probe would move up and down to create flow in the water cavity to increase heat transfer. This mode would only be usable once the probe has melted a significant portion of the ice since the entire probe needs to be submerged in water to properly create circulation. Once power is supplied to the heat probe, it will be lowered into the ice as more water melts. After the water is melted, it will be extracted through a hole in the center of the probe via a peristaltic pump.

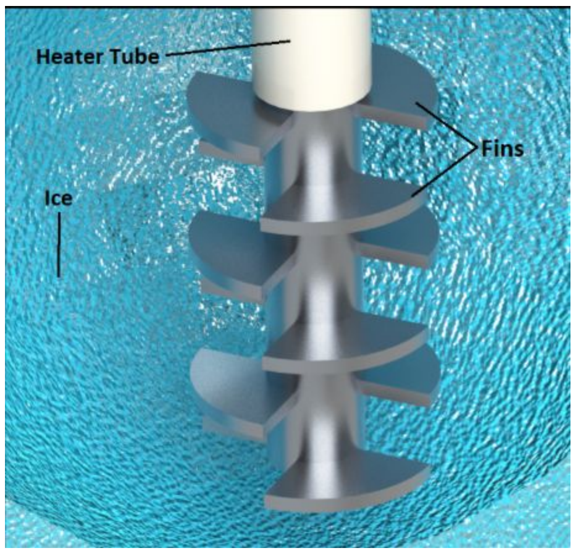


Figure 3: Heat Probe Rendition

2.3.4. Digital Core Systems Technique

The drill will be collecting data while penetrating the overburden layers to construct a digital core of the subsurface. The drill has four sensors attached to it: one hall effect sensor, one torque sensor, one compression-strain gauge, and one string potentiometer. The hall effect sensor is used to measure the drills RPM by counting how many times the auger spins in the presence of a magnetic field. The compression gauge is used to measure WOB and the string potentiometer will give vertical distance information. This data is being collected through the myRIO DAQ and stored as an exportable file. From there the drilling data is taken into Matlab where it is cleaned to reduce noise and is displayed more graphically.

2.3.5. Filtration and Water Collection System

The primary method of filtration is gravity settling assisted by electroflocculation. The Solinst 410 Mark 4 peristaltic pump (with a flow rate between 120 mL/min and 3.5 L/min through ⅝ inch tubing) will push water into a settling tank continuously while there is water available from the hole or until the maximum volume capacity is reached. A pair of aluminum meshes within the tank will be wired up to a 12V power source and will function as a cathode and anode for the electroflocculation. Oxidation will occur at the anode, releasing electrons that will attract contaminants to themselves, and form larger flocs, or clumps, that will settle to the bottom more quickly with their increased mass. Once sufficient settling has occurred, determined via visual assessment and/or readings from a turbidity sensor, a solenoid valve will open and allow filtered water to exit out of the side of the settling tank. A valve on the bottom of the tank will open and allow built-up sediment to release back into the testbed to free up the tank for the next round of settling and prevent clogging of the system. The filtered water will then enter a second stage of filtration, passing through the peristaltic pump once more and then through a series of progressively finer stainless steel meshes. The meshes have open areas of 67%, 65%, and 49% respectively and are installed in 3D-printed housing units that can easily be replaced or removed if clogging occurs. After both stages of filtration, the clean water will finally be delivered to the collection bucket.

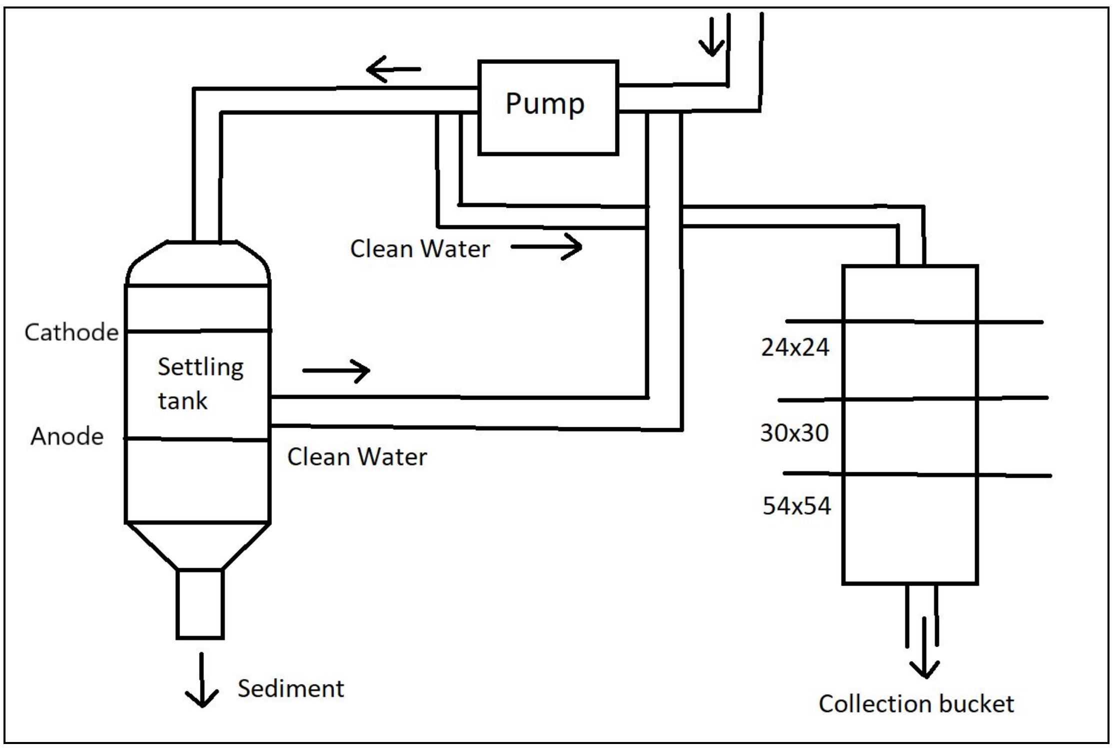


Figure 4: Filtration System

2.3.6. Overburden Layers Solution

A slow and steady approach has been adopted when drilling the initial hole. Initially, the drill will be kept at half power. Most of the variation in penetration rates will be determined by the rate of the linear actuator. We do not expect the need to pause and raise the drill upon encountering harder terrain. There is a possibility that debris may begin to clog the flutes of the auger; especially between the borehole casing wall. Should this occur during the competition, the auger will be removed and spun quickly to clear the drill before re-entering the wellbore. Upon encountering a troublesome layer, the linear actuator will be pushed to its limit before the drill is sped up. This will benefit the team in keeping the total amperage at a reduced amount. If the opportunity presents itself, the drill can be manually changed to percussive mode only. Putting the hammer down will break up rock for several moments (and fracture the obstruction) before returning to rotary mode.

2.3.7. Temperature Changes Solution

There is no expectation the drill will freeze. The vibration from the drill in the rotary hammer function should deter the auger from becoming solidified to the soil bed; especially when the drill is in percussive only mode. However, the drill will not cease to operate as long as the drill is in the pocket and this alone should mitigate the risk of the soil arresting the auger.

2.3.8. Control and Communication System

Our system is controlled by LabVIEW's real-time engine. The system's linear rail subsystem can be controlled using three separate PWM wave channels from the DAQ. These are fed through a stepper motor which controls the linear rails directly. Speed can be controlled by changing the on off cycle ratio of the PWM. We can monitor how far the drill has moved in the lateral direction by using the feedback from the string potentiometer. The drill has on/off control as well as variable speed. This can be used to carefully drill through overburden layers. For feedback control our most important drill sensor is the WOB sensor. This will be used to monitor how much instantaneous force is applied with the drill bit which will help to stay under NASA's competition limit. In addition a current sensor is placed on the main power line running into the drill to make power limits are not exceeded. Pump LabVIEW controls include the ability to turn the pump on/off as well as changing the direction of the pump. In addition, filtration valve control is enabled by a PWM going into the servo aray.

2.3.9. Datalogger

As previously mentioned the drill has a variety of sensors attached, all of them recording data through our myRIO DAQ. Some of the sensors are digital. These include the string potentiometer, the WOB sensor, and the torque sensor. These are feeding directly into the DAQ's digital I/O feeds. The hall effect sensor is analog and has to run through a signal booster before it can be read using the DAQ's analog inputs.

2.4 Technical Specifications

Table 1: Total System Constraints and Technical Specifications

Mass (kg)	Volume (m^3)	Length of Drill Bit (m)	Max Operating WOB (N)		Chassis Rated Load (N)	Max Drilling Speed (rpm)	Torque (N*cm)			On-board computer system	Communications Interface	Software	Max Power Draw (W)
			Auger	Heat Probe			Drill	Horizontal Stepper Motor	Vertical Stepper Motors				
59	2	.914	95	80	2200	1050	5500	35	90	Windows 10	NI MyRIO	LabVIEW	936

3. <u>Design Changes/Improvements</u>

The casing for the drill was changed in a few important ways since the mid point review. We realized we would have an issue with the initial design when leaving the casing in the overburden layers. Without a way to prevent the auger from slipping deeper into the dirt and therefore submerge the casing too deep to be removed by the upper part of the casing. Too prevent this from happening we added a disk shaped stopper to the lower casing as seen in Figure 5(a). The piece which connects the upper and lower auger was also redesigned to have only two attachment points rather than the original four (see Figure 5(b)). Concerned about the connection piece breaking we sized up the pieces and make fewer of them. The new design (see Figure 5(c)) should also make it easier to line of the drill casing when attaching and removing the casing during the drilling sequence. The last major change to the casing was a redesign of the clamp that holds the upper casing to the auger itself. The original design had a smooth surface that attaches to the auger, see Figure 5(d), however the smooth surface was not able to provide enough grip to hold the casing in place and would slip. The new design (see Figure 5(e)) has rigid points that can hold the auger much tighter and the overall thickness of the part was increased to allow us to tighten the casing to the auger with greater force. The new clamp design significantly improved the grip strength and we do not expect to have more issues with slippage. The overall design for the new casing assembly can be seen in Figure 5(f).

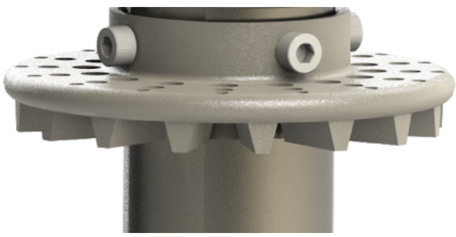


Figure 5(a): Casing Stopper

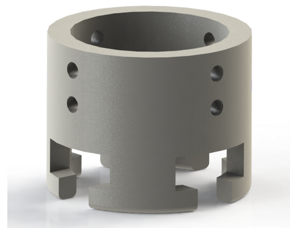


Figure 5(b): Original Connector

Figure 5(c): New Connector

Figure 5(d): Original Clamp

Figure 5(e): New Clamp

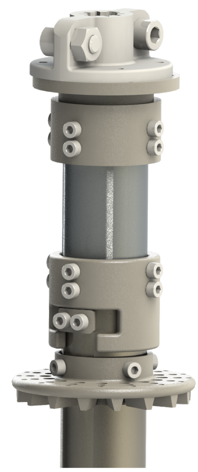


Figure 5(f): New Casing Assembly

4. <u>Challenges</u>

The challenges that have encompassed the whole project have consisted of acquiring components in a timely manner to integrate them into the overall system. This has included manufacture lead time for customized parts. Deducing the cause of electrical failures has been another prevalent issue especially earlier on in the project. At this stage of the design process we have isolated and remediated nearly all of the electrical issues we had and expect to eliminate any issues in the final weeks.

There has been some difficulty ensuring a smooth lock/unlock of the spin lock mechanism of the wellbore casing. The challenge was not an operational failure, rather it was completing the operation in a timely manner. However, debris has not obstructed the components because the mechanism remains above ground and the drill creates very fine particles while operating on hard surfaces. The operation will be calibrated to produce a quicker transition time by means of inputting different values into the program and noting the differences. Once this is calculated, the process should be streamlined.

The melting portion of the system have seen difficulty in integrating the heat cartridges obtained to be functional with the heat probes designed. The cartridges were not designed to be submerged in liquid water and a severe insulation process needed to occur to adapt the cartridge for the current needs and team's desires of water collection. The process to solve the issue was done by implementing various means of waterproofing the heat cartridges and testing their effectiveness. It was resolved by dipping the leads into a liquid electrical tape solution and securing the cartridges into the heat probe with a silicone epoxy.

5. Overall Strategy for the Competition

Across the two days the competition takes place the primary concern is to ensure maximum water collection. An initial hole will be drilled and quickly followed up with the heater probe to provide maximum exposure with the underground ice. A secondary hole will be drilled shortly after the heater probe is situated in the primary borehole, which will then be used to record the digital core sample. The secondary hole can be drilled much slower to ensure accurate readings of the seperate layers of regolith while also serving as another potential site to collect water should we find the initial hole becomes harder to extract water than an untapped hole could provide.

A sleeve will be deployed initially and upon a better understanding of the type of soil the team is up against, the sleeve may not need to be used in additional drilled holes. Last year's team recommended the inclusion of a sleeve design after they experienced a partial collapse of the cavity. This ensures a clear path to the subsurface ice. A pocket of water will form upon sinking the heat probe further into the ice and after some time, the peristaltic pump will be turned on to evacuate the melted ice through the filtration system and finally into the scoring bucket. The heat probe can be lowered further to create another cavity and repeat the process. Separate holes can additionally be drilled to repeat this process at different locations around the test bed allowing for a greater amount of water collection.

6. Summary of Integration and Test Plan

Each subsystem was tested individually for a better understanding of the components of each system, and to determine which options are most viable for the goals of the competition. Once the requirements of each subsystem were dictated, they were assembled through various custom adapters. The drill will be attached to the structure with the aid of an aluminum clamp, which holds it to a load cell attached to one of the vertical linear actuators. The heat probe will be clamped to a pipe to allow for wires and tubing to safely travel to their respective designations. The tube is then attached to a custom adaptor, which is 3D printed for this application to optimize weight and strength, and attached to the second vertical linear actuator. The pump and settling tank will be placed near each other on the side of the structure which allows for ease of maintenance should any complications arise.

The testing was completed in separate stages prior to a full system test before the competition to isolate and remediate problematic subsystems. The heat probe and pump were tested together by submerging the heat probe into a container of ice at a rate of one inch per minute. A teardrop shaped cavity began to form below the ice during testing as expected and after about 15 minutes, enough melted ice had accumulated where we tested our water extraction subsystem and drained the chamber accumulating over 100 mL of liquid. The chamber was measured to be about 3 inches deep and 2 inches wide in its widest section. During the competition the heat probe would be

The drill was tested multiple times using a clay-rock mixture during the month leading up to the final report with good results. Once fully integrated into the electronic system, the new test resulted in slightly unstable oscillations of the drill as shown in the video from modifications made since the initial testing. A torque sensor added below the motor would provide a second point of contact eliminating the shakiness and is scheduled to be integrated in the following days. All computer code runs smoothly and has mostly been debugged. The final two weeks leading up to the competition will focus on final debugging, enhancing our filter system, and ensuring all previously tested systems are operating flawlessly.

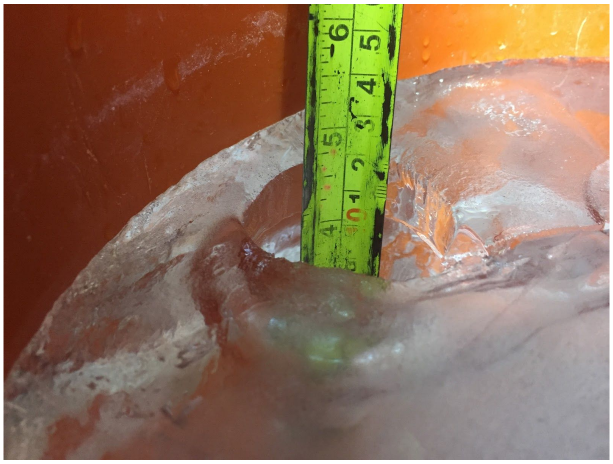


Figure 6(a) & 6(b): Heat Probe Melt Depth

7. Tactical Plan for Contingencies/Redundancies

The drill and pump both face similar risks for becoming stuck while in operation. If the drill becomes stuck in any of the various layers of overburden or ice then it can be reversed. In the event that the pump becomes clogged, then reverse flow operation will be attempted. If reverse operation fails to free up the tubing passing through the pump then the tubing itself can be swapped out.

The filtration system has several options for risk mitigation. If it turns out that settling time exceeds reasonable operational time limits then primary filtration can be shifted to the mesh system. If these meshes become clogged and impede flow to the collection bucket then there are several options. There is a surplus of steel mesh that can be used to replace clogged filters. If the supply of steel mesh is exhausted and/or the filters simply do not allow enough water flow then the filters can be removed outright.

Item / Function	Potential Failure Mode(s)	Potential Effect(s) of Failure	Sev	Potential Cause(s)/ Mechanism(s) of Failure	Prob	Current Design Controls	Det	RPN	Recommended Action(s)
Drill bit	Breakage/cracks due to extreme forces	Inability to drill new holes	7	Human error, misreading pressure sensors	3	Pressure sensor, visible strain of drill	3	63	Ensure that first drilled hole is done slowly, ensuring excessive pressure forces do not occur
Heating probe	Excessive heating, power surge, structural cracks	Inability to heat ice	6	Improper power allotment	2	Heating sensor	2	24	
Drill structure	Rough transportation to Virginia, falls off an elevated surface, excessive weight of subsystems	Inability to support subsystem attachments	6	Improper packaging for transport, excessive subsystem mass	2	Monitoring mass of subsystems	1	12	Ensure drill is packaged properly and driving is done safely
Peristaltic pump	Clogging, electrical failure	Inability to pump water	5	Pump diameter too small, limited pump power	4	Pump feedback	3	60	
Tubing	Clogging from sediment	Clogged tubing prevents further water collection	4	Tubing size too small, not preventing build-up of sediments	5	Visual inspection of tubing	4	80	Complete adequate testing to ensure clogging of the tube will not occur
Filtration system	Excessive sediment, poor filtration of sediment	Dirty Water	2	Inefficient filtration design	3	Visual inspection of filtration system and filtered water	1	6	
Water collection system	Clogging, control failure	Improperly pumped water, inability to pump water	4	Large chunks of sediment	4	Larger diameter tubing prevents clogging	3	48	
Coding	Bugs in coding	System crashes	5	None	4	Good coders	2	40	Double/triple check code
Various Sensors/Controls	Improper wiring/voltage break	System crashes, doesn't read data properly	5	Damage to sensors/cheap sensors	3	Expensive sensors	4	60	

Figure 7: Contingency Planning

The table to the left is the Failure Modes and Effects Analysis (FMEA) design verification process the team chose to help identify potential failure modes and the effects they would have on the entire system. The analysis calculated a final score by multiplying the severity of the failure times the probability the failure could occur times the ability to detect the failure. In the appendix the ranking of each of the three analysis are included. By determining the systems with the greatest threats of failure, the team was able to focus time and energy combatting the more urgent problems identified.

8. Project Timeline

Table 2: Project Timeline

Task	Task Description	Start	Finish	Duration (Days)
1	Initial Concept Overview	10/03/18	10/11/18	8
2	Decompose Design Into Subsystems	10/11/18	10/16/18	5
3	Concept Feasibility Calculations	10/16/18	11/14/18	29
4	Basic Prototyping and Modeling	10/16/18	11/14/18	29
5	Create CAD Drawings of Subsystems and Assembly	10/25/18	12/07/18	43
6	Concept Critique and Final Design Decision	11/07/18	11/14/18	7
7	Project Plan Submittal	11/15/18	11/15/18	0
8	Prototype Heat Probe and Extraction Assembly	11/15/18	11/28/18	15
9	Setup Drilling/Auger Test Rig	11/21/18	11/30/18	9
10	Begin Testing and Data Collection for Heat and Extraction Systems	11/28/18	12/07/18	9
11	Begin Testing and Data Collection for Drilling Test Rig	11/30/18	12/07/18	7
12	Construct Frame and Actuation Systems	11/30/18	12/07/18	7
13	Develop Control System Using LabView	11/30/18	1/25/19	56
14	Create Wiring Diagrams for Electronics	1/09/19	1/16/19	7
15	Finalize Subsystem Designs	1/09/19	3/19/19	70
16	Integrate Subsystems Into Final Assembly	3/01/19	3/26/19	26
17	Create Video of Design	3/08/19	3/11/19	3
18	Mid-Point Review Submittal	3/14/19	3/14/19	0
19	Preliminary Testing of Assembly	3/15/19	3/29/19	14
20	Resolve Issues Found During Testing	3/29/19	4/19/19	21
21	Perform Failure Analysis and Purchase/Manufacturer Spare Parts	4/19/19	5/03/19	14
22	Finalize Design and Finish Testing	4/19/19	5/19/19	30
23	Technical Paper and Integration Video Submittal	5/19/19	5/19/19	0
24	Competition at NASA Langley Research Center	6/03/19	6/07/19	4

9. Safety Plan

The entire system will include a 9-amp fuse as required by the competition as well as an 8-amp breaker to ensure the team does not exceed the limit. All wiring has proper insulation surrounding it to avert accidental electrocution. The wiring around the heating probe poses the greatest electrical threat due to its close contact with water and will be the most heavily insulated piece of equipment. The drilling subsystem carries the chance of projectiles ejecting from the drill bed and so safety glasses and close-toed shoes have been worn during all testing that has carried out. We plan on carrying out these same safety protocols for the competition. No hazardous chemicals or materials are present meaning the only safety concerns from our system come from either an electric shock or materials being discharged from the drill, both of which are an extremely unlikely occurrence.

10. Paths-to-Flight

Water extraction on Mars and the moon pose a plethora of difficulties which needs a specially designed system to overcome the challenges. Instead of adhering to competition rules, such as a limits on mass, volume, weight on bit, and power draw, constraints will instead be based on the logistics of transporting the drill to the surface of the moon/Mars and operating effectively in each environment. More components may be added to compensate for non-terrestrial conditions, but mass and volume should still be minimized to keep the cost of launching low. Power will need to be solar or nuclear, and each come with their own limitations. The major benefit of solar power is the theoretical capability to run indefinitely, as long as dust interference can be mitigated. Radioisotope thermoelectric generators have powered numerous missions to space over the past few decades, however that depends on a reliable surplus/source of plutonium. The excavation site would need to be sealed for both environments to maintain a manageable system to extract water. Electronics would have to be radiation hardened for protection during transit An aluminum heat probe would be utilized for both environments for its thermal properties while having a low density which minimizes weight.

10.1 Mars

The Martian environment varies greatly from that on Earth and presents the team with new challenges involved in the task of collecting water that would need to be accounted for. For starters, Martian temperatures vary between -153 degrees Celcius at the poles and 20 degrees Celsius at the equator throughout the year [2]. On average the temperature is roughly -63 degrees Celsius [3]. Atmospheric pressure on Mars is also less than one percent that of Earth's, roughly 6 millibars versus the over 1000 millibars enjoyed on Earth [4]. The lowered temperatures and atmospheric pressures will greatly affect the mechanical interaction between the drill and the overburden as well as most subsystems. The pull of gravity is 3.71 m/s^2 on the surface of Mars [3], one-sixth that of Earth's, which will result in both advantages and disadvantages for the FIRE drill.

For the mounting system, the 6105 aluminum alloy that composes the structure is capable of withstanding the full range of Martian conditions. Ideally, however, the structure could be made of a stronger material to increase the longevity and reliability of the mission, given weight and cost restrictions from NASA. This could include potential metals such as an aluminum-lithium alloy much like the Orion MPCV (Multi-Purpose Crew Vehicle) or other similar metals such as titanium alloys which have both high strengths and low density to maintain a light weight [5]. Should the system be delivered to Mars in a similar manner to past rover missions, the structure would need to be designed with an increased thickness to be capable of withstanding entry into the Martian atmosphere. The system is expected to be mounted on a rover and share a similar entry method where parachutes would deploy initially to decrease its approach velocity, before receiving assistance from several rocket engines to stabilize its final landing. Every system will need to be enclosed to ensure its functionality and longevity. Mars is known to have severe dust storms at all times throughout the year which would interfere with certain mechanical functions such as the linear rails and with a build up prevent the system from working properly. The rails would need a flexible cover which can translate with the motion of the carriages to provide continuous protection while it is running. The covers would be on rollers which can reel up either side of the carriage and maintain tension needed to provide its protection. Should there be any dust buildup after a dust storm, running the auger at maximum power for a short time would provide the system with enough vibrations to shake off any area with excessive buildup. Should solar panels be utilized, it would be vital to keep them clear of Martian wind-blown dust. A series of linear actuators should be installed to allow the panel to maintain its perpendicularity with the sun, using the linear actuators, tilting the panel away from the direction of the storm would minimize build up. In addition, placing an off-balanced wheel on a motor would provide the solar panel with agitation to promote the movement of particles on its surface.

For the excavation system, a drill sleeve will be necessary for use on Mars except in locations where ice is close to the surface. Across wide areas of the plant, the Martian soil is very dry and dusty [6]. Through our experience in testing, even encountering a coarser layer of soil will result in the pulverization of the material which leads to difficulty of maintaining the hole integrity. Because of this factor, it would be critical to have a sleeve which can support the soil around the dirt and protect the excavation site for continuous water collection. FIRE Drill was designed with the intention of having a sleeve be retrievable and reusable for multiple cycles. The locking mechanism provides an easy interaction between the sleeve and the rest of the system. The holesaw tip on the sleeve should also aid with the installation of the sleeve but should be designed such that the tip is easily replaceable after a few hundred cycles to maintain system effectiveness. The sleeve would also hold a magnet while the auger has a Hall effect sensor to ensure alignment for the casing to its locking mechanism to reduce any error for sleeve retrieval. An infrared optical sensor was considered for this alignment and would likely be more accurate to align, the drilling process may interfere with the visibility and reliability with optic based sensors which is why the magnetic field sensor was chosen. Additionally, the lower surface and subsurface temperature will increase the compressive strength of the rock being removed [7]. This may result in stronger drill forces required, either maximizing the strength of the existing drill or selecting another drill with higher weight on bit capabilities. Above is a picture of a hole drilled by Curiosity on Mars last April and shows how grainy Martian regolith is [8].

Figure 8: Hole Drilled on Windjana by Curiosity on Mars

For the water extraction system, the hole developed is structurally stabilized with the sleeve, which was drilled down with the auger to aid in protecting the heat probe and minimizing water contamination for extraction. The probe itself would need multiple temperature sensors to closely monitor the progress of water temperature. While extracting liquid water is plausible in the environment, the atmospheric properties of Mars poses a minimal margin which will see the option as easily feasible. The pressure and temperature on the Martian surface will place water right near its triple point, leaving only two degrees of play before the melting ice will sublimate (as shown in figure 8 below). As the heat probe increases the temperature of the ice, there is a good chance liquid water will be bypassed entirely and sublimation would occur. In an attempt to maximize the system's efficiency, it would be ideal to create an air-tight excavation site where any resulting water vapor could be collected. Collecting water vapor would potentially simplify the pumping and filtration processes. With a sealed extraction site, the water vapor would also allow the chamber to build up pressure prior to running the pump, the pressure would then aid in obtaining the water through the conventional means developed for the competition. Most systems, if not the entire drill system, would need to be encased in protective shielding to protect from dust and Martian winds, however any tubing would need to be protected and thermally insulated to maintain the water in a liquid or gaseous state. Another complication from the issue of such a small range for liquid water on Mars is that the heat probe can no longer provide a convection aspect to its heating. The heat probe was initially designed to give the added benefit of heating a pool of water with the aid of agitating the water, because the pool of water on Mars will be very minimal, there are negligible gains from keeping the current design. The heat probe sent to Mars can be designed in a minimalistic sense now without fins and with the sole purpose of protecting the heat cartridges while pumping water from the excavation site. This will dramatically reduce the weight and volume of this subsystem.

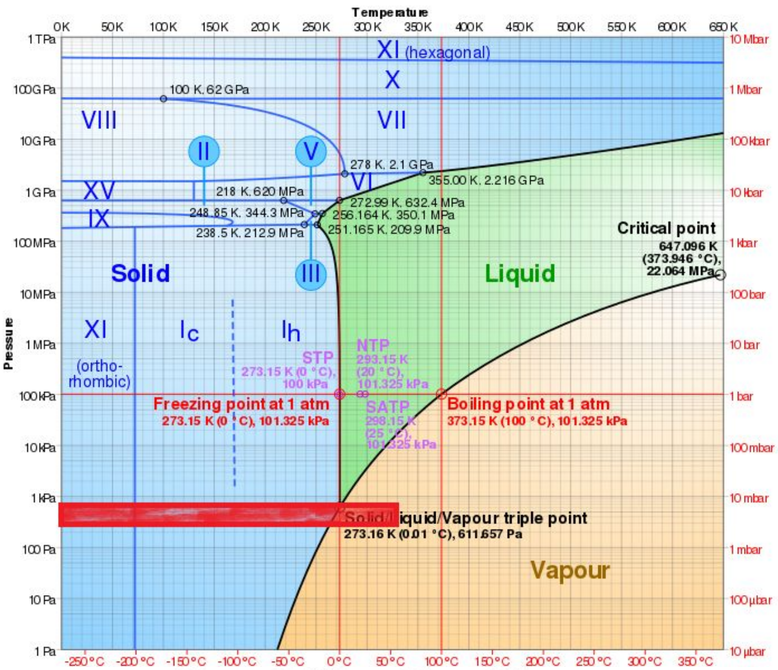


Figure 9: Water Phase Diagram

The filtration and water collection system would have to be equipped to handle water in its liquid and gaseous forms. Any water vapor collected would have to be condensed using something like a cold trap that can maintain pressures high enough for stable liquid water. For the first stage of filtration with liquid water, settling time would be greatly increased due to Mars' lower gravity. Even with electroflocculation creating flocs of higher mass, the settling tank still relies on gravity to pull the contaminants to the bottom. Larger and/or multiple settling tanks could be utilized, however this would most likely increase the mass and/or volume of the system. When water is collected through the conventional means (liquid state), the existing series of meshes would be utilized to eliminate the amount of solids in the water tank. The meshes when implemented on Mars would be 3D printed to allow for ease of maintenance and prevent the need to keep an inventory of certain parts. Once the water has passed through the original stages of filtration, it would still need to undergo a sublimation and condensation process to eliminate the heavy chlorides known to be in high concentrations on Mars [9].

For the control and communication system, the best way to improve the system for use on mars is to add completely autonomous controls. In addition to this the DAQ should be upgraded to something similar to a compactRIO. Programing the sensory inputs and constructing an autonomous system could be done much more efficiently and more accurately using compactRIO modular I/O. In addition, programs would need to be written that allow the RIO system to run without the help of a user interface.

10.2 Moon

Much like the challenges Mars requires us to account for, the moon offers a different set of challenges as well. The moon's temperatures vary primarily on whether or not the surface is receiving sunlight. This ranges between -153 degrees Celsius during nighttime and 107 degrees Celsius during the day [10]. Unlike Mars, the moon has close to zero atmosphere present. This produces the obvious problems of ice sublimating when heated to higher temperatures. As a result, no ice is present on the surface of the moon except at each of the poles where sunlight hasn't reached the bottom of some of these craters in millions, if not billions of years. The picture above shows where trace amounts of surface ice are believed to be present in the south pole [11]. Last year's regular RASC-AL competition winners, who were also from the Colorado School of Mines, focused their mission on exploring the Cabeus crater as a primary site to extract water from the surface [12].

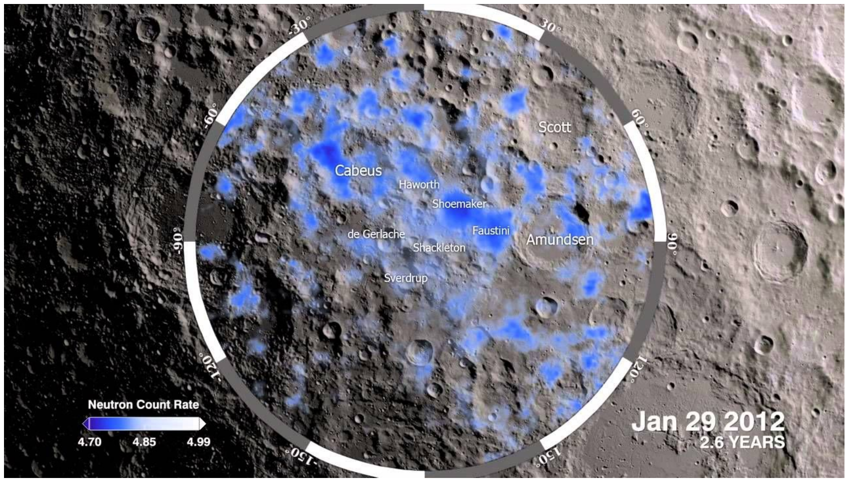


Figure 10: Lunar South Pole

The mounting system for the heat probe and water collection would need to be adapted to sustain the new temperature range. The tubing for the pump and the pipe used to attach the heat probe would need to be able to resist the massive temperature range. Currently the peroxide cured silicone tubing used for the peristaltic pump has an operating temperature of -65 degrees Celsius to 200 degrees Celsius. The upper range of this is close to where we would run the temperature to, however the lower bound is not low enough to function at the Moon's temperature. The tubing would require a heating hose covering it to protect its functionality. The mounting apparatus for the heat probe is currently a PVC pipe, because it is not being used to maintain pressure, the main concern would be from its melting and deformation. Making this piece from metal would decrease the efficiency of the heat probe on the ice because of its leniency to conduct the heat to the rest of the system. The attachment pipe should be made of a thermally insulative material which has a high melting point such as carbon fiber that would remain structurally stable to 200 degrees Celsius.

There are several unique challenges to prospecting and extracting water on the Moon that is different from both Mars and Earth. As it pertains to the water-ice extraction on Moon, the permanently shadowed regions on the North and the South poles have been noted to be the most attractive. The form of water-ice is largely unknown and the quantity of water-ice ranges from 5.6% [13] to 30% [14]. There is a significant lack of understanding of the subsurface stratigraphy in these regions. This significantly affects the complexity of prospecting on Moon.

The most important factors in exploring the system design for lunar conditions are the environmental conditions at the lunar surface. The Moon has a hard vacuum of the order of 10^{-13} torr and temperatures ranging from 40K to 270K [15]. At these conditions, fluids will freeze or sublimate very quickly making the extraction more challenging. The hard vacuum will also affect the functionality of our pumps. Since pumps work by utilizing a pressure difference with the outside atmosphere, our pump would not work on the Moon as is. Another solution, other than pressurizing the entire system, would be to convert the FIRE drill to collect water vapor. Once collected, the vapor would be moved to a cold trap.

The vacuum on the Moon also affects the drilling mechanics itself by changing surface friction and heat dissipation. Since the moon is in a vacuum the lack of surface oxides could potentially increase the friction between the surface and the drill bit making drilling a little easier [15]. The vacuum also prevents heat from being absorbed by any type of atmosphere meaning that the FIRE drill will need to rely solely on radiation to cool its systems. Another challenge that the Moon brings to the drilling operation is its low gravity. The gravity directly affects the force with which the drill bit can press against the surface formation. Since the gravity on the Moon is much lower, the available WOB for the same platform mass will also be lower. This can cause ROP drop or increased vibrations affecting the FIRE Drill and its ability to produce an accurate digital core. One way of mitigating this without increasing the weight, and subsequently the cost, of our system, would be to devise a method of anchoring the drill to the surface and employing methods to provide axial force externally.

Since little to no information is available for the subsurface geotechnical properties of the lunar polar regions, the methods used to prospect on the moon must account for possible variability. The prospecting methods should be tested extensively for different subsurface stratigraphy at lunar conditions to evaluate the accuracies of different methods.

11. Budget

The funding received came in several installments. The Colorado School of Mines Senior Capstone Program - \$ 1,000, NASA RASC-AL - \$ 10,000, and sponsorship funding from ProtoLabs for manufacturing purposes - \$ 3,079 of \$ 6,000. At several weeks before the competition spending has surpassed our initial expectation of \$ 11,000 by 18%, with an another estimated \$ 600 yet to be made in purchasing. The summary of expenses is shown below in Table 2 and does not include materials already in possession from the outset of the project.

Category	Spending
Tooling and Supplies	$133.24
Structure	$239.88
Drilling & Excavation	$422.55
Digital Coring	$2,560.66
Control System	$149.75
Heating & Filtration	$1,732.55
Sponsorship Manufacturing	$3,079
Travel & Logistics	$3,297.80
Total	**11,615.43**

Figure 11: Budget

References

[1] SPE-178842-PA.pdf (in drive)
[2] *NASA Quest > Aerospace ::* [Online]. Available: https://web.archive.org/web/20130607140708/http://quest.nasa.gov/aero/planetary/mars.html. [Accessed: 20-May-2019].
[3] *NASA*. [Online]. Available: https://nssdc.gsfc.nasa.gov/planetary/factsheet/marsfact.html. [Accessed: 20-May-2019].
[4] J. Schilling, *Mars General Circulation Modeling Group @ NASA Ames*. [Online]. Available: https://web.archive.org/web/20070707084855/http://www-mgcm.arc.nasa.gov/mgcm/HTML/WEATHER/pressure.html. [Accessed: 20-May-2019].
[5] “Aluminum Goes to Mars,” *Aluminum Goes to Mars | The Aluminum Association*, 17-May-2019. [Online]. Available: https://www.aluminum.org/aluminum-goes-mars. [Accessed: 20-May-2019].
[6] T. Sharp and T. Sharp, “What is Mars Made Of? | Composition of Planet Mars,” *Space.com*, 12-Dec-2017. [Online]. Available: https://www.space.com/16895-what-is-mars-made-of.html. [Accessed: 20-May-2019].
[7] K. A. Zacny and G. A. Cooper, “Coring basalt under Mars low pressure conditions,” The Mars Journal, vol. 3, pp. 1–11, 2007.
[8] D. Spector, “This Is A Really Cool Picture Of A Hole On Mars,” *Business Insider*, 01-May-2014. [Online]. Available: https://www.businessinsider.com/curiosity-rover-drilling-on-mars-2014-5. [Accessed: 20-May-2019].
[9] Bright Exposures of Chloride Salt on Southern Mars. (2008, March 20). Retrieved from https://www.nasa.gov/mission_pages/MRO/multimedia/pia10248.html
[10] J. Rocheleau, “Temperature on the Moon - Surface Temperature of the Moon,” *Planet Facts*, 19-Jun-2014. [Online]. Available: http://planetfacts.org/temperature-on-the-moon/. [Accessed: 20-May-2019].
[11] *NASA*. [Online]. Available: https://svs.gsfc.nasa.gov/4057. [Accessed: 20-May-2019].
[12] “Colorado School of Mines Poseidon Final Technical Paper,” *rascal.nianet.org*. [Online]. Available: http://rascal.nianet.org/wp-content/uploads/2018/07/2018-RASCAL-Final-Technical-Paper_31_Colorado-School-of-Mines-POSEIDON.pdf. [Accessed: 05-Mar-2019].
[13] A. Colaprete, P. Schultz, J. Heldmann, D. Wooden, M. Shirley, K. Ennico, B. Hermalyn, W. Marshall, A. Ricco, R.C. Elphic, D. Goldstein, D. Sammy, G. D. Bart, E. Asphaug, D. Korycansky, D. Landis, L. Sollitt, “Detection of Water in the LCROSS Ejecta Plume”, Science, Vol 330, Issue 6003, pp. 463-468
[14] S. Li, P. G. Lucey, R. E.Milliken, P. O. Hayne, E. Fisher, J. Williams, D. M. Hurley, R. C. Elphic, “ Direct evidence of surface exposed water ice in the lunar polar regions”, PNAS, 115 (36), September 4, 2018, pp :8907-8912
[15] K. A. Zacny and G. A. Cooper, “Friction of drill bits under Martian pressure,” Journal of Geophysical Research, vol. 112, no. E3, 2007.

Appendix

Effect	SEVERITY of Effect	Ranking
Hazardous without warning	Very high severity ranking when a potential failure mode affects safe system operation without warning	10
Hazardous with warning	Very high severity ranking when a potential failure mode affects safe system operation with warning	9
Very High	System inoperable with destructive failure without compromising safety	8
High	System inoperable with equipment damage	7
Moderate	System inoperable with minor damage	6
Low	System inoperable without damage	5
Very Low	System operable with significant degradation of performance	4
Minor	System operable with some degradation of performance	3
Very Minor	System operable with minimal interference	2
None	No effect	1

FMEA Analysis: Severity of Effect Ranking

PROBABILITY of Failure	Failure Prob	Ranking
Very High: Failure is almost inevitable	>1 in 2	10
	1 in 3	9
High: Repeated failures	1 in 8	8
	1 in 20	7
Moderate: Occasional failures	1 in 80	6
	1 in 400	5
	1 in 2,000	4
Low: Relatively few failures	1 in 15,000	3
	1 in 150,000	2
Remote: Failure is unlikely	<1 in 1,500,000	1

FMEA Analysis: Probability of Failure Ranking

Detection	Likelihood of DETECTION by Design Control	Ranking
Absolute Uncertainty	Design control **cannot** detect potential cause/mechanism and subsequent failure mode	10
Very Remote	**Very remote** chance the design control will detect potential cause/mechanism and subsequent failure mode	9
Remote	**Remote** chance the design control will detect potential cause/mechanism and subsequent failure mode	8
Very Low	**Very low** chance the design control will detect potential cause/mechanism and subsequent failure mode	7
Low	**Low** chance the design control will detect potential cause/mechanism and subsequent failure mode	6
Moderate	**Moderate** chance the design control will detect potential cause/mechanism and subsequent failure mode	5
Moderately High	**Moderately High** chance the design control will detect potential cause/mechanism and subsequent failure mode	4
High	**High** chance the design control will detect potential cause/mechanism and subsequent failure mode	3
Very High	**Very high** chance the design control will detect potential cause/mechanism and subsequent failure mode	2
Almost Certain	Design control **will** detect potential cause/mechanism and subsequent failure mode	1

FMEA Analysis: Likelihood of Detection