Virginia Tech Ice Extractor
V-TIE

Not Pictured: Austin Richter, Kevin Shinpaugh

Team Members:
Vu Nguyen [1]
Minzhen Du [1]
Jake Rosenthal [1]
Joshua Smoot [1]
Noel Sheaffer [1]
Austin Richter [2]

Virginia Polytechnic Institute and State University

Faculty Advisor:
Kevin Shinpaugh [3]

---

[1] Undergraduate, Virginia Polytechnic Institute and State University, Aerospace and Ocean Engineering Department
[2] Undergraduate, Virginia Polytechnic Institute and State University, Mechanical Engineering Department
[3] Professor, Virginia Polytechnic Institute and State University, Aerospace and Ocean Engineering Department

Table of Contents

List of Figures

List of Tables

Nomenclature

PLC	= Programmable Logic Controller
V-TIE	= Virginia Tech Ice Extractor
WOB	= Weight on Bit

1. Introduction

With the discovery of water ice harbored beneath the surface of Mars, the possibility of inhabiting that distant world seems more within our reach than ever before. If this ice were to be excavated, it can be liquefied for human consumption or, perhaps, converted into oxygen for breathing or fashioned into rocket propellant. Technology which can perform ice extraction is now highly desired, the development of which would be yet another step closer to embarking on this interplanetary journey. The Virginia Tech Ice Extractor (V-TIE) is designed to accomplish this goal.

The nexus of the V-TIE systems is a compartmentalized auger drill with a step bit and two detachable blades, surrounded by a transport tube. The step bit and blades divert large particles of overburden and gravel from being ingested into the auger as well as reduce ice into shavings. The design of the auger separates the volume within the sheath into four compartments. As the drill penetrates the overburden, two compartments accept the incoming dirt while the other two compartments are shielded. Once the drill reaches the ice, the drill is rotated such that the closed compartments open, simultaneously closing off the dirt compartments. The drill then proceeds to collect the ice. Thereafter, the ice is delivered to the filtration system.

The filtration subsystem employs ultrasonic vaporizers to generate clear water vapor from a dirt/water mixture. When the chamber which contains the vapor is pressurized, the vapor exits through an elbow connection and condenses upon collision with that 90-degree turn. The resulting water flows through a tube to the collection bucket. When filtration is complete, the bottom of the chamber can be separated to access and remove the remaining dirt.

The drilling and filtration subsystems are supported by a frame of 20x20 mm and 20x40 mm aluminum extrusions. The drill is transported laterally via two stepper motors and timing belts, and vertically by two linear shafts, bearings, and a ball screw shaft, powered by a stepper motor.

V-TIE is chiefly powered by a 24V DC, 480W power supply and powered by one Arduino Mega 2560 and one Arduino DUE. The weight-on-bit is tracked by a second Arduino Mega 2560. The Arduino Mega 2560 will also be logging the power consumption of the system.

V-TIE is 98.5cm x 98.5cm x 169cm and 39.2kg, and consumes a maximum of 388W.

2. System Description

2.1. Drilling Module

2.1.1. Drill Bit and Auger Configuration

The drilling module comprises a drill bit, auger, and external tube (Figure 1). As a hole in the overburden is excavated, dirt will be ushered into the auger by the drill bit and conveyed upward by the auger. When ice is reached, the bit reduces the large block into shavings, which are contained within the auger.

The drill bit consists of an ABS plastic conical blade mounting body and two triangular, detachable cutting blades, manufactured from A2 tool steel plate. Two channels guide encountered material into the auger. The step bit prevents the largest particles of the overburden from being ingested, decreasing the possibility of a jam occurring. The blades shave the ice into a fine, snow-like powder.

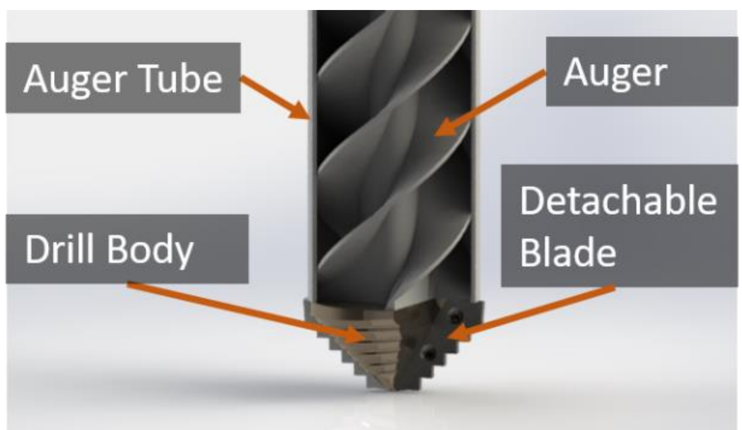

Figure 1. Drill Bit and Auger Configuration.

The ABS plastic auger divides the internal volume of the tube into four discrete compartments (Figure 2) - two for ice and two for overburden. Stepper motors rotate the auger independently of the drill bit. As drilling occurs, the drill bit rotates synchronously with the auger such that material may enter only one type of compartment - either dirt or ice - while covering the entrances to the remaining two compartments.

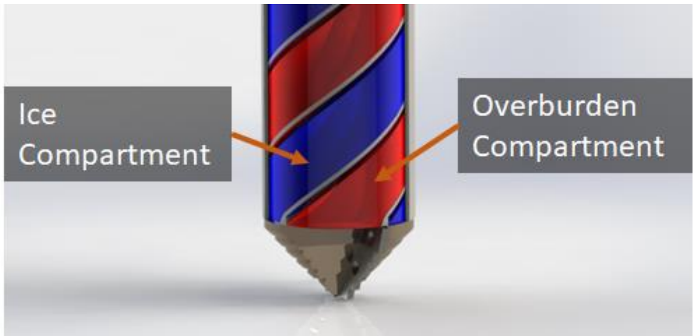

Figure 2. Depiction of Compartments.

Drilling commences with the overburden compartments open. As the drill penetrates the overburden, the material is ingested by the auger and expelled out of an opening at the top. Once the drill reaches the ice layer, the auger will be independently turned 90˚ to align the ice compartments with channels in the drill bit (simultaneously closing off the overburden compartments). The drill then proceeds through the ice, collecting the ice shavings in the designated compartments. Once the drilling has ceased, the auger is again rotated to contain the collected ice while the drill is backed out of the drilled hole.

2.1.2. Pin Limiters

During drilling operations, when the drill encounters material, its rotation will slow, whereas the auger continues rotating at its initial rate. Consequently, the auger will overtravel, and thereby, the compartments will become misaligned with the channels in the drill bit. Remedying this issue, two pins are fixed to the bottom of the auger and ride in 2 slots in the back of the drill bit, shown in Figure 3. The pins function as limiters, preventing the overtravel of either drill bit or the auger during drilling. Additionally, the pins serve as hard stops when switching compartments. The overburden compartments are aligned with the drill bit by rotating the drill bit clockwise while the auger remains stationary. When the rotation is halted by the pins, alignment has been achieved. The ice compartments are aligned by rotating the drill bit counterclockwise until the pins are contacted.

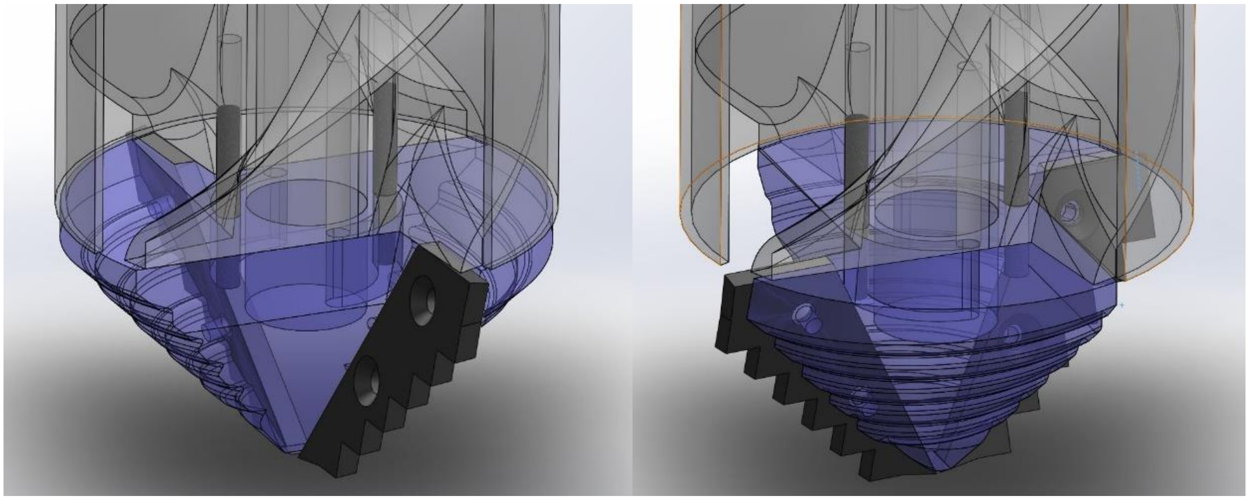

Figure 3. Pin Configurations.

2.1.3. Force on Bit Sensors

Real-time weight-on-bit (WOB) data is collected with the use of four strain gauges (Figure 4) in order to fulfill the corresponding requirement and ensure that the 150N maximum WOB is not exceeded. The gauges are installed between the ball screw nut and the motor mounting platform. Each is rated up to 50 kg and has an internal resistance of 1000 Ohms.

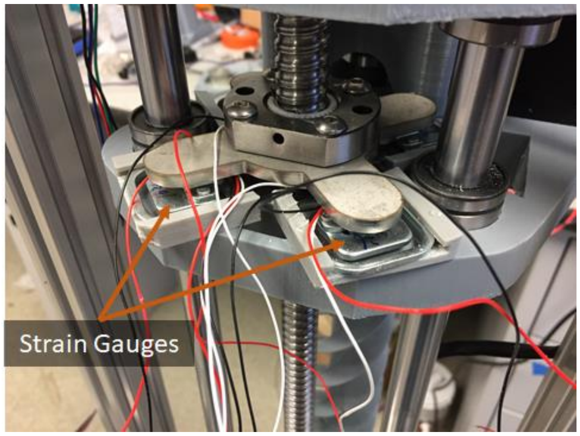

Figure 4. Strain Gauges.

2.2. Water Heating and Filtration System

2.2.1. Filtration and Heating

The filtration system (Figure 5) comprises two chambers. The ice and dirt collected is first deposited into an open receptacle at the top. The conical component is then pushed upward as the attached linear actuator is extended, allowing the materials to enter the upper chamber; thereafter, the actuator is retracted to seal off the chamber.

The lower chamber contains ultrasonic vaporizers, ceramic pads which vibrate at high frequencies. The pads break off particles of water from the chamber above and produce water vapor. The vaporizers are contained separately from the collected material to prevent contact with dirt, which can impede proper functioning. Water is used as a transmission fluid, carrying the ultrasonic vibrations upward through the lower chamber, such that they penetrate the thin, plastic top and vaporize the collected water in the upper chamber. (Note: The water that is used for transmitting the ultrasonic vibrations was implemented during the assembly of the filtration subsystem. This water does not interact with the ice collected.) While the vaporizers are active, substantial heat is generated, where reduces the ice to water. Clean water vapor is yielded from the potentially-contaminated water in the upper chamber, leaving any dirt on the bottom surface of the chamber. When air is pumped into the upper chamber, the vapor inside flows from the chamber through an elbow connection. The vapor collides with the 90-degree turn with sufficient velocity as to condense the water vapor. The resulting water is, subsequently, conveyed by a 0.25” tube to the competition collection bucket.

Figure 5. Filtration Subsystem.

Once all of the water is vaporized, condensed, and expelled from the upper chamber, dirt may remain on the bottom surface of the upper chamber. This dirt can be removed from the filtration subsystem. First, the vaporizers are disabled. Then, a linear actuator pulls the lower chamber downward into a stabilizing sheath. Finally, a stepper motor moves a brush across the surface and removes excess dirt from the system. After cleaning, the actuator is extended and the chambers are rejoined. The upper chamber is sealed by an internal O-ring which interfaces with the top surface of the lower chamber.

2.3. Actuation

2.3.1. Vertical Axis

The vertical actuation is achieved by two linear shafts, bearings, and a ball screw shaft. The rotation of the ball screw by a stepper motor directs the drill module along the shafts.

2.3.2. Horizontal Axis

The horizontal forces which move hardware laterally are applied by two stepper motors. Two timing belts extend from each stepper motor to the opposite side of the structure, where they are positionally fixed and rotationally free. The weight of the drill is supported by two 20x40 mm aluminum extrusion and attached thereto by wheel brackets, which minimize friction during relocation procedures. The drill is attached to each timing belt via clamps.

2.4. Programming and Control

2.4.1. Microcontroller Selection

An Arduino and a Raspberry Pi were considered for implementation in V-TIE. The former has a processing speed of 700 MHz, whereas the latter has a lower processing speed, at 16 MHz. A high processing speed is desirable, as it decreases lag time. The lower speed notwithstanding, the Arduino has open source hardware, and is, therefore, much easier to code. Furthermore, the Arduino is preferable because it is able to convert analog to digital inputs and outputs.

Although the Arduino is limited in the languages with which it can operate, open source hardware renders coding less onerous. Finally, an Arduino capable of real-time data tracking, which is requisite for logging WOB. For the foregoing reasons, the team has decided to use the Arduino, which was coded in C++ and scripted in Arduino IDE.

2.4.2. Control Implementation

The nexus of control is an Arduino Mega 2560, which orchestrates the actuation and filtration. An Arduino DUE microcontroller is responsible for operating the stepper motors associated with drilling. These two Arduinos work in tandem to concurrently operate the drill and vertical actuation. The WOB is tracked by a second Arduino Mega 2560 and logged by a second computer. The power consumed by V-TIE is tracked by this Arduino, with the use of a shunt resistor and an Analog Devices AD8215 current sensing amplifier. The Arduino code is executed by PuTTY.

2.5. Electrical and Power Schematic

2.5.1. Description

The electronics of V-TIE (Figure 6) were designed with a 35% margin as to lessen the likelihood of exceeding 1200 W and 10 A. V-TIE employs a 24V DC, 480W power supply as the main power source. Since the air compressor used to pressurize the filtration system requires 12V DC, a DC-DC converter was implemented to regulate the voltage from 24V to the required 12V. Printed circuit boards were fabricated to create more reliable connections between electrical components.

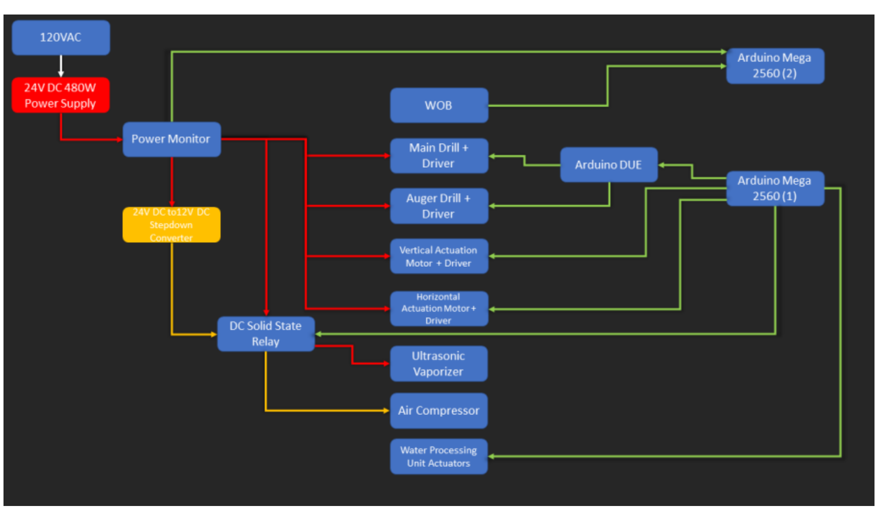

Figure 6. V-TIE Electrical Block Diagram.

2.6. Structure

2.6.1. Description

The main structural frame for V-TIE is composed of 20x20 mm and 20x40 mm T-slotted aluminum framing. This material was selected for its low mass and ease of use. Additionally, many connectors and attachable components are commercially available that make the assembly process simple.

The base of the structure is a 980x980 mm square with plate connectors in each corner holding it together. The vertical portion of the structure is 840 mm tall; it is held together and connected to the base by plate connectors, brackets, and corner connectors. The horizontal actuation system is integrated with the vertical part of the structure and attached to the drill-auger assembly. The vertical portion of the structure is also supported by four diagonal 20x20 mm slotted aluminum framing pieces to increase stability. The panel on which the electronics are mounted is attached to the diagonal beams behind the drilling module. Furthermore, a frame was constructed and attached to the base of the structure with brackets to support the water filtration system.

2.6.2. Test Bed Mounting

V-TIE will connect to the test station with four 4" long ½-13 threaded bolts, which pass through two modified 20x40 mm sections of slotted aluminum framing. One bolt is inserted in each corner of the base of the system.

3. Technical Specifications

Table 1. Technical Specifications.

Overall Mass		Kilogram	39.2		
Overall Volume	Length	Meter	0.985		
	Width	Meter	0.985		
	Height	Meter	1.69		
Length of Bit		Meter	0.945		
Maximum Weight on Bit		Newton	100		
Rated Load	Drill Module	Max. Voltage (V)	48	Max. Current (A)	6
	Filtration	Max. Voltage (V)	24	Max. Current (A)	7
	Vertical Actuation	Max. Voltage (V)	48	Max. Current (A)	3
	Horizontal Actuation	Max. Voltage (V)	24	Max. Current (A)	4
Maximum Drilling Speed		RPM	~250		
Maximum Torque		Newton-meter	8		
On Board Computer System	2 Arduino MEGA 2560 and 1 Arduino DUE				
Communications Interface	USB to Arduino MEGA 2560				
Software	Arduino IDE and PuTTY				
Power Consumption		Wattage	388		

4. Design Changes/Improvements

4.1. Structure

The structure experienced appreciable vibrations during operation of the drilling module. This circumstance may negatively affect the efficiency of the drill. In order to lessen the vibrations, tensioned metal cables were added to the structure (Figure 7). These cables were effective, at first; they loosened over time, and efficacy was lost. The tension cables were ultimately replaced with angled beams (Figure 8).

Figure 7. Tension Cables.

4.2. Drill Module

Figure 8. Angled Beam Connectors.

The first iteration of the drill bit design exceeded the capabilities of local manufacturing facilities. Therefore, the bit was redesigned to reduce manufacturing complexity, comprising a simpler step bit body made of ABS, and a steel cutting blade (Figure 8). 3D-printing the drill bit body allowed fabrication, testing, and modification to occur more rapidly as compared to other means of production. When the number of compartments in the auger was increased from two to four - two compartments for ice and two for overburden – the number of blades, correspondingly, increased from one to two.

The cutting angle of the drill bit blade was altered to improve performance. Drill bits commonly have cutting angles ranging from 45 to 90 degrees. The ideal cutting angle for the purposes of V-TIE is 75 degrees - the angle at which the torque required to cut is minimized. [1] The bit was redesigned to utilize this angle, which improved drilling performance (Figure 9).

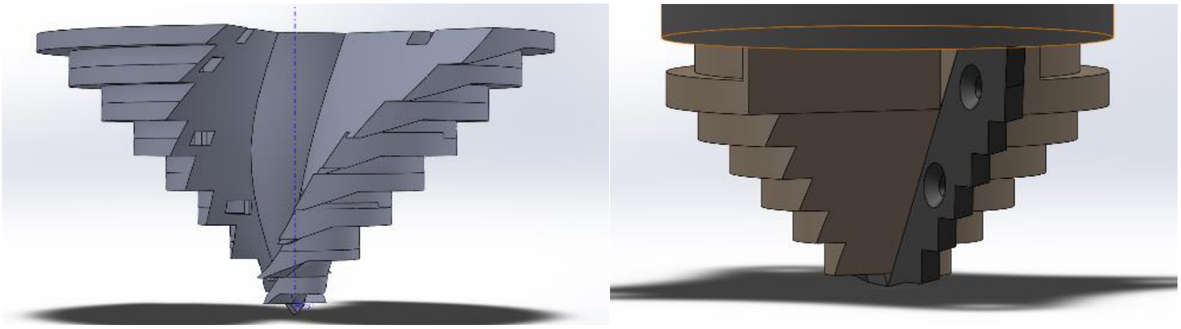

Figure 9. Progression of Drill Bit Design.

4.3. Programming and Control

Initially, a programmable logic controller (PLC), in conjunction with one Arduino MEGA, was planned to control V-TIE. A PLC is equipped with greater numbers of input and output pins than an Arduino, but these extra pins were not necessary, and an Arduino is capable of executing the requisite logic to operate V-TIE. As the system developed, an additional Arduino MEGA and an Arduino DUE were added to operate the filtration subsystem and conduct real-time data tracking.

5. <u>Challenges</u>

5.1. Ice Buildup in Drill Module

The initial design of the drill module utilized a Forstner bit to shave and collect ice. During preliminary testing, extracted ice shavings built up in the bit and bottom of the auger, rather than being conveyed upward (Figure 10). Experiments were conducted in which the pitch of the auger was varied, in efforts to improve the flow rate of material. The influence, however, of adjusting the pitch was minimal. After switching to a custom drill bit, modeled to the geometry of the auger, the ice buildup no longer occurred.

Figure 10. Forstner Bit Ice Shaving Blockage.

5.2. Filtration Regeneration

Initially, a gravity-based filter, in which water passes through various layers of mesh, was planned to be employed for the means of filtration; however, this method decreases the longevity of a

V-TIE mission; over time, dirt would accumulate in the filter, slowly decreasing filtration efficacy. Therefore, a regenerative filtration method, employing ultrasonic vaporizers, was developed to prevent curtailing the lifetime of V-TIE. Two challenges were encountered in the filtration redesign effort: designing a means of condensing the water vapor generated, and designing a mechanism which expels the dirt from the subsystem. Various techniques of condensing water vapor were tested (e.g. a radiator for computer water cooling systems). Ultimately, condensation was achieved by accelerating the flow to a high velocity by generating a pressure differential, and then, directing the vapor through a sharp turn. A prototype was developed to prove this concept (Figure 17 Appendix). In removing the dirt, the primary issue was maintaining the integrity of the O-ring with which the vaporization chamber is sealed. The risk of losing O-ring efficacy was mitigated by safeguarding the O-ring inside the vaporization chamber while lower chamber is pulled downward by a linear actuator and cleaned of debris.

6. Overall Strategy for the Competition

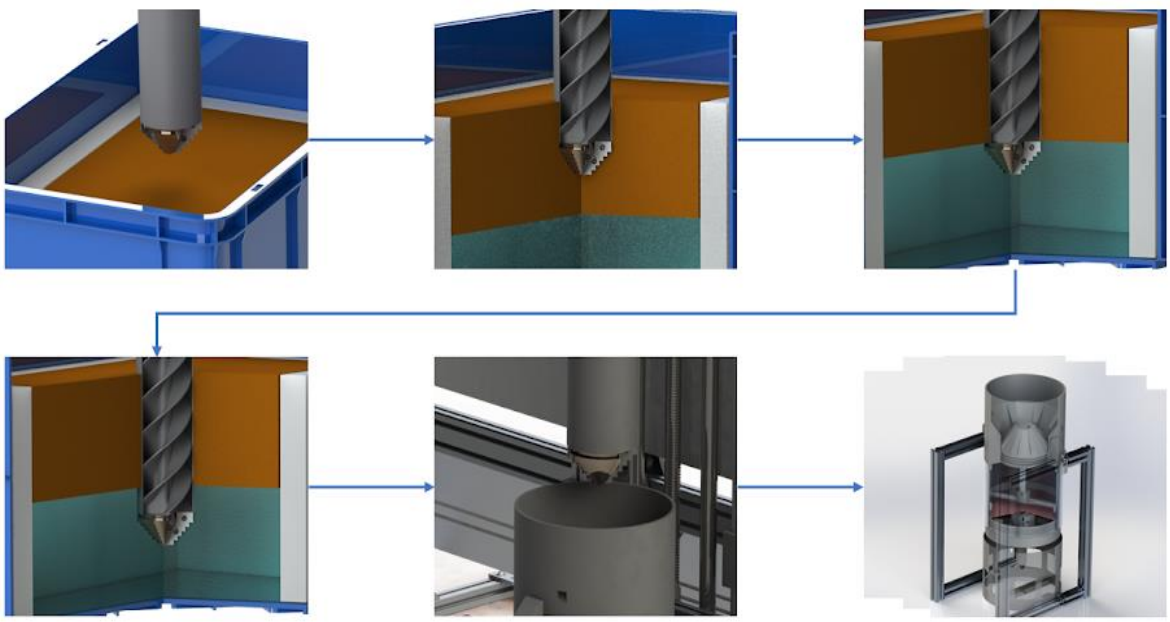

Figure 11. Concept of Operations.

Throughout drilling operations (Table 2), the WOB and power consumption are constantly monitored as to inform the ways in which V-TIE is commanded. The drill will descend toward its prescribed depth until a WOB of 100 N is reached, at which point, vertical actuation will pause. (Note: The WOB of 100 N was selected in accordance with a factor of safety of 1.5.) The drill will then continue rotating until the WOB decreases, after which, drilling is resumed. If the power consumption exceeds 1200 W or 10 A, the drill will be halted, and thereafter, proceed downward at a slower plunging rate.

Table 2. Drilling Stages.

Stage	Material	Compartment	RPM	Vertical Actuation	Description
1	Overburden	Overburden	0 RPM	0 m	Align overburden compartment.
2	Overburden	Overburden	~30 RPM	+0.2 m	Drilling through overburden until bit is submerged.
3	Overburden	Overburden	~250 RPM	+0.3 m	Increase RPM of drill.
4	Overburden	Overburden	~250 RPM	0 m	Pause vertical actuation while overburden within auger is expelled through top.
5	Ice	Overburden	~30 RPM	+0.2 m	Descend through ice until the compartment openings are below the top of the ice.
6	Ice	Overburden	0 RPM	-0.1 m	Drill ascends slightly.
7	Ice	Ice	0 RPM	0 m	Compartments are switched.
8	Ice	Ice	~30 RPM	+0.3 m	Drilling proceeds; ice is collected. Drilling ceases when maximum vertical travel is reached.
9	Ice	Ice	0 RPM	-0.1 m	Drill ascends slightly.
10	Ice	Overburden	0 RPM	0 m	Compartments are switched. Ice is contained within the auger.
11	Ice	Overburden	0 RPM	-0.8 m	Extract ice from test hole

After the drill is extracted with ice contained in the auger, the drill module is transported horizontally such that it becomes aligned with the filtration subsystem. The compartments are switched from dirt to ice before the drill bit and auger are swiftly rotated, back and forth, to expel the collected ice downward. The filtration process (Table 3) then commences.

Table 3. Filtration Stages.

Stage	Compressor	Bottom Linear Actuator	Top Linear Actuator	Vaporizers	Description
1	Off	Extended	Extended	Off	Ice is introduced.
2	On	Extended	Retracted	On	Vaporization begins. Vapor condenses. Water is delivered.
3	Off	Retracted	Retracted	Off	Lower chamber divorced from upper chamber. Stepper motor brushes dirt from lower chamber.
4	Off	Extended	Extended	Off	Chambers are rejoined.

7. Summary of Integration and Test Plan

The drilling subsystem, actuation subsystem, main structure, and electronics have been integrated. Initial actuation testing demonstrated the effective functioning of the timing belts and stepper motors in laterally transporting the drilling and vertical-actuation subsystems. The ball screw and stepper motor were capable of supporting the drilling subsystem and exerting 100N of force downward (i.e. WOB).

Drilling testing through overburden demonstrated the successful operation of the conical drill bit, which prevents large pieces of overburden and gravel from entering the auger (Figure 12). The auger elevated all of the dirt ingested and expelled it from the bored hole. Next, the drill was presented with bare ice in order to determine the efficacy of the geometry of the drilling blades and the cutting angle. V-TIE yielded successful results in the testing of its capabilities to drill through ice, and contain and expel the ice shavings. Finally, V-TIE was tasked with navigating through overburden to access and extract ice. The drill penetrated the overburden, as previously seen. The overburden compartments were successfully closed; the ice compartments were opened. As the drill advanced through the ice, the mixing of the ice and overburden into thick clay caused the cutting blades to lose contact with the ice. Consequently, drilling capability was lost. Modifications to the drill bit have remedied this issue. Through the aforementioned testing, a strategy for drilling through overburden and ice was developed (Section 6).

Figure 12. Overburden Testing.

8. Tactical Plan for Contingencies/Redundancies

8.1. Hardware Failure

If hardware fails during operation, V-TIE may not be able to function. Spare drilling-module, structural, and electronic components will be available during the operation of V-TIE to serve as replacements should their counterparts fail in action.

8.2. Drill Stall

If the drill fails to push away gravel in its path, it will come to a sudden stop. Additionally, if the drill is descending too quickly through overburden or ice, the drill will, likewise, cease rotation. Should either of these situations occur, the drill bit will halt while the auger continues to rotate. Consequently, the alignment between the drill-bit channels and auger compartments will be lost. Thereupon, the drill will be moved upwards and the appropriate compartments will be realigned. Drilling will then proceed downward. This process of retracting the drill, realigning the compartments, and resuming drilling will be performed three times. If failure persists, then drilling operations in that location will be abandoned. Subsequently, a new location will be selected, wherein drilling will commence.

8.3. Auger Jam

The auger will halt if dirt or gravel becomes lodged between the auger and the surrounding tube. Should this occur, the drill bit and auger will cease to rotate while the auger continues to rotate; the drill-bit channels and auger compartments will also become misaligned. Thereupon, the drill will be moved upwards and the appropriate compartments will be realigned. The drill bit and auger will then be rotated vigorously, to and fro, in an effort to expel the lodged material. This operation may be performed numerous times before drilling proceeds.

8.4. Drill Freezing

Due to low temperatures in which the drilling takes place, there is a potential for ice to melt and refreeze while in contact with the drill bit. If this were to occur, the drill bit becomes immobilized, encased in ice. Teflon spray was applied to the drill bit and auger to prevent water and ice from adhering to the hardware. Drilling tests with the Teflon spray were conducted to prove that drill bit freezing is not an issue.

9. Project Timeline

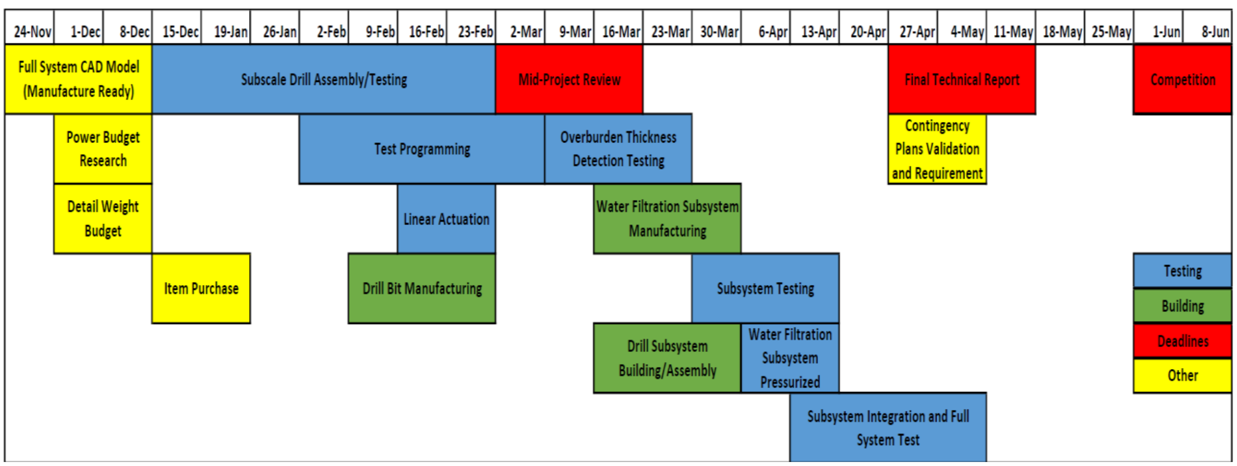

Figure 13. Timeline.

10. Safety Plan

10.1. Electronics

Electronic equipment and wiring can be dangerous if improperly handled. In order to mitigate the risk of electric shock, all electronics must be powered off before work on the system is permitted.

10.2. Stay-Out Zone

A four-foot stay-out zone is in effect while V-TIE is in operation.

10.3. Drill Bit Blades

The drill is equipped with sharp metal components, which can puncture unprotected skin. The drill blades may be handled only if the system is not powered and protective gloves and glasses are worn.

10.4. Chemicals

Teflon spray was applied to the drill and auger. The spray is intended to prevent overburden and ice from sticking to the hardware. Ingestion of this chemical may be harmful.

11. <u>Path-to-flight</u>

11.1. V-TIE Modifications

11.1.1. Materials

The Earth-based system designed for the competition will be performing in a hangar at NASA Langley; ambient temperatures range from 25°C to 35°C and lower temperature range from -10°C to 0°C in the test station. Therefore, several critical components must be modified for the Martian environment, in which temperature range from -60°C to 27°C.

11.1.1.1. Drill Bit

The 3D-printed drill bit will be exchanged for a drill bit composed of grade 5 Titanium alloy, which is highly resistant to wear and corrosion.

11.1.1.2. Drill Blades

The cutting blades that are attached to the drill bit will be changed from A22 steel to tungsten carbide. Tungsten carbide can withstand lower temperatures than steel without losing effectiveness or becoming brittle.

11.1.1.3. Auger

The auger for the Earth-based V-TIE system was 3D printed with ABS plastic to minimize weight and cost. The auger for the Mars-based system will be fashioned from of aluminum to be more durable.

11.1.1.4. Timing Belts

The timing belts used in the horizontal actuation modules and drilling module are made of rubber embedded with high tensile strength fiber. For a Mars mission, the timing belt will be reinforced by steel wires.

11.1.1.5. Teflon Coating

Teflon coating is used as lubrication on the Earth-based system such that the extracted regolith/ice can flow through the auger easily. However, the harsh Martian environment and the long expected service life of the Mars-based system necessitates a more corrosive/wear resistant coating. Nickel-Boron plating is suitable for the task. Plating of this variety is commonly used in high wearing/impacting parts, such as high-loading gears and rotating/reciprocating bolts for firearms. Nickel boron can be electroplated onto the metal components of the Mars-based V-TIE - the auger, drill bit, and drill blades.

11.1.2. Pressurization for Ice Melting

The pressure on the surface of Mars is approximately 6.1 mbar - 1% of the surface pressure on Earth. Consequently, the subsurface ice will sublimate immediately if exposed to the atmosphere. Figure 14 shows that on the Martian surface, water exists in a gaseous phase. Therefore, water ice, when exposed to the low pressure, will transform into a vapor.

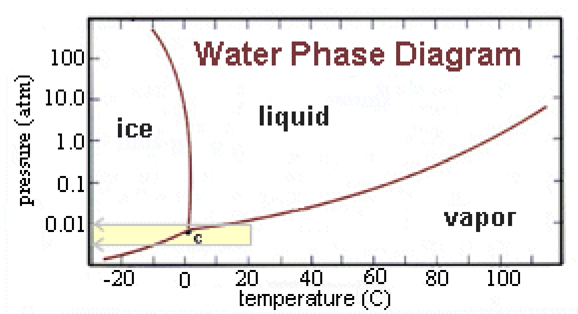

Figure 14. Water Phase Diagram

Due to sublimation, the water filtration system must be altered from its Earth-based design. On Earth, the ice collected is directly entered into the vaporization chamber. Should the vaporization chamber be opened, likewise, to the Martian atmosphere, all of the ice already contained within the chamber would sublimate. In order to prevent this occurrence, a mechanical sealing lid must be added to the filtration subsystem (Figure 15), which establishes an airlock chamber. This intermediate chamber will accept the ice from the drill while the vaporization chamber remains sealed. After airlock is closed, the seal between the two chambers is broken, permitting the ice to enter the vaporization chamber.

Figure 15. Filtration Subsystem Concepts

11.1.3. Transmission Fluid in Filtration System

Furthermore, the transmission fluid used to carry the ultrasonic vibrations must be changed. Water is used in the Earth-based design; however, this liquid will freeze on Mars. Another fluid must be selected which can effectively transmit the sound waves and withstand the low Martian temperature.

11.1.4. Ice Detection

The Mars-based V-TIE will be equipped with a measurement-while-drilling device, which provides real-time-data and ice-detection capabilities. [2] Instrumentation will be integrated which is able to distinguish the refractive properties of ice from those of overburden. V-TIE will, therefore, determine when a compartment switch transpires. Since the ice on Mars will not be pure, the refractive index of the ice will be 1.35-1.40. [3]

11.1.5. Code

Due to the significant and variable distance between Mars and Earth, there exists a communication delay - a minimum of about 4 minutes and a maximum of about 24 minutes. [4] Therefore, the code employed for Earth-based operation, which requires constant human involvement, must be augmented to establish autonomy. Foremost, this effort necessitates the integration of code for the operation of ice-detection instrumentation and its cooperation with compartment changing.

11.1.6. Controls

Microprocessors employed in interplanetary missions must be low in mass, volume, and power consumption. Additionally, such microprocessors must acquire data in real time and withstand the radiation which bombards the Martian surface. Proven to work on the Mars Curiosity Rover, the RAD750 is able to fulfill the foregoing requirements and is comparable to the primary Arduino used by V-TIE (Table 4). [5] [6]

Table 4. Arduino vs. RAD750

	Clock Speed	SRAM	EEPROM	Mass	Radiation Hardened
Arduino MEGA 2560	16 MHz	8 KB	4 KB	36 g	No
RAD750 6U Compact PCI	110-132 MHz	4-48 MB	4 MB	1220 g	Yes

11.1.7. Communication

Stationed on Mars, V-TIE will communicate with Earth with an ultra-high frequency antenna. Transmissions from the system will be captured by NASA's Mars Odyssey and Mars Reconnaissance Orbiter, and relayed to the Deep Space Network.

11.1.8. Dust Protection

If left unprotected, the hardware composing V-TIE is vulnerable to airborne dust. For the Mars-based system, aluminum covers will be manufactured for the motors which operate the drill, and horizontal and vertical actuation. Additionally, bellows will envelop the ball screw, preventing dust particles from interfering with the operations of the ball bearings.

11.1.9. Heating Element

The filtration subsystem of the Earth-based version of V-TIE does not employ a heating element to melt the collected ice. Rather, the ambient temperature, in tandem with the heat generated by the operation of ultrasonic vaporizers, is relied upon to reduce the ice to liquid. On Mars, however, the low ambient temperature must be combated with the application of electronic heating elements in order to melt the ice.

Three temperature sensors will also be implemented to effectuate a feedback control system for temperature regulation. Each sensor will be placed 60° apart on the inner wall of the vaporization chamber. One sensor is sufficient for temperature regulation; three sensors establish redundancy in the subsystem. Should a sensor failure occur or large amounts of ice cling onto a sensor, poor temperature control will not result in subsystem damage.

11.1.10.Power

The Earth-based prototype of V-TIE uses a traditional wall outlet to supply its power. On Mars, two 300W Poly-Crystalline Solar Panels will power V-TIE. Each panel operates at 37.5 V and 8 A, which will supply sufficient power for full operation of V-TIE. The solar panels are suitable for spaceflight, as they are low in mass and volume; a single panel has a mass of 23kg and a surface area of about 2 m^2. The Poly-crystalline solar panels can also withstand extreme weather conditions and temperatures as low as -40°C. [7]

11.1.11.Water Containment

The water yielded by V-TIE will undergo a containment process (Figure 16). Both tanks A and B are pressure-regulated by an electric pressure relief valve. The pressure in tank A and the pressure of the filtration subsystem will be maintained at a ratio such that the water vapor flows from the vaporization chamber and through the elbow connection, condensing into a liquid. Then, the liquid in tank A will be pumped into and stored in tank B.

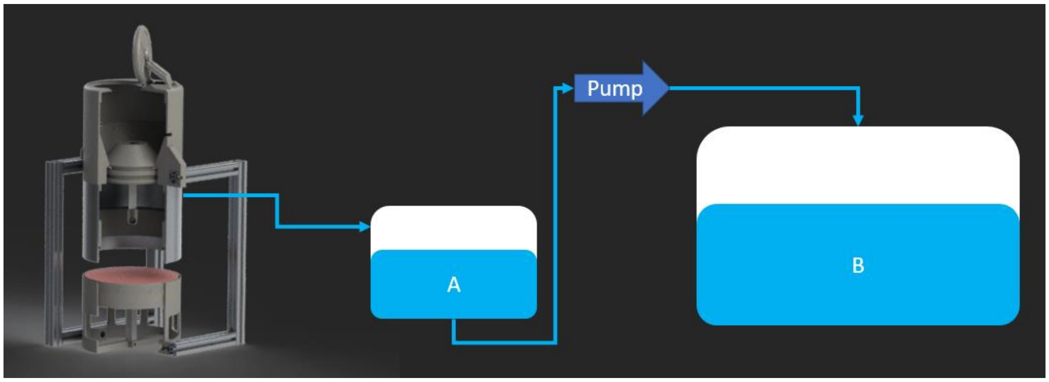

Figure 16. Water Containment Concept.

11.2. Mission CONOPS

11.2.1. Launch Vehicle

The mass of the Mars-based version of V-TIE is estimated to 124.4 kg. (The frame will be made of titanium, which is approximately twice as dense as the aluminum that the Earth-based system uses, and the auger will be made of plated aluminum, which is about twice as dense as the 3D printed ABS that the Earth-based system uses.) The Atlas V is a suitable launch vehicle, as it capable of launching an object with the mass and volume of V-TIE on a trajectory to Mars.

11.2.2. Landing Site Selection

The Utopia Planitia region on Mars is an ideal location for the deployment of V-TIE. In this region, the Mars Reconnaissance Orbiter's Shallow Radar has revealed substantial ice deposits beneath the surface. Buried under 1 to 10 meters of soil, the ice is just out of reach of V-TIE, in its current state; however, extending the drill will enable V-TIE to access this subsurface ice. (Significant changes to the length entails structural augmentations and motor upgrades, increasing the mass and power consumption.) The Utopia Planitia, furthermore, comprises flat terrain, suitable for a landing. [8]

11.2.3. Entry, Descent, and Landing

Upon entry, the V-TIE system, encapsulated a backshell and heat shield, will be guided by small rockets towards the targeted location on the Martian surface. Parachutes are deployed to decelerate the vehicle and the heat shield is jettisoned. V-TIE is further slowed and guided by retro-rockets until landing occurs. Additional landing stages - an auxiliary parachute, an airbag, the sky crane maneuver, etc. - may be implemented in accordance with the requirements of the selected method of deployment. [9]

11.2.4. Deployment

V-TIE can be deployed onto the Martian surface in many different ways; the optimal form depends on the scope of the mission and the current phase of humanity's exploration of Mars.

If a sizable ice deposit were located at a significant depth, then a lander mission is more suitable for ice collection than a rover mission. An immobile structure can support a much longer drill, which can access ice at great depths. The landing of V-TIE, in this case, must be very precise, coming to rest directly above the selected ice deposit.

Integrating V-TIE with a rover mission, as opposed to a lander mission, begets a larger potential for water collection. Equipped with mobility, V-TIE is able to survey a large area of the Martian surface, locate ice, and yield water from numerous locations. This arrangement is advantageous for scientific and exploratory missions in which the locations of ice deposits are unknown. If many small ice deposits were found spanning large areas of the Martian surface, the rover based V-TIE is able to maneuver to the ice deposits and collect water from them all.

12. Budget

The V-TIE team would like to express its gratitude to the Kevin T. Crofton Department of Aerospace and Ocean Engineering of Virginia Polytechnic Institute and State University for the kind contribution of $5,000 as well as NASA for a $10,000 grant. As of May 17, 2018, the total expenditures sum to $12,623.67 (Table 5).

Table 5. Expenditures.

Category	Spending
Tools	$3,800.01
Structure	$1,806.33
Drill Module	$1,538.59
Programming & Control	$1,596.64
Filtration & Heating	$922.86
Travel and Logistics	$2,959.24

13. References Cited

[1] Talalay, P. G., "DRILL HEADS OF THE DEEP ICE ELECTROMECHANICAL DRILLS" Available: https://icedrill.org/Documents/Download.pm?DOCUMENT_ID=793

[2] "How Does Measurement-While-Drilling (MWD) Work?," *RIGZONE Empowering People in Oil and Gas*Available: https://www.rigzone.com/training/insight.asp?insight_id=296&c_id=.

[3] Warren, S. G., "Optical constants of carbon dioxide ice," *Captcha*Available: https://www.osapublishing.org/ao/abstract.cfm?uri=ao-25-16-2650.

[4] "Time delay between Mars and Earth," *Rocket Science*Available: http://blogs.esa.int/mex/2012/08/05/time-delay-between-mars-and-earth/.

[5] BAE Systems, "RAD750 6U CompactPCI single-board computer," *RAD750 6U CompactPCI single-board computer*.

[6] Mantech.co.za, "Arduino MEGA 2560 ," *Arduino MEGA 2560* .

[7] "100W Solar Panel | Invensun," *Invensun: Change The World*Available: https://www.invensun.com/solar-panels/100w-solar-panel.

[8] "Mars Ice Deposit Holds as Much Water as Lake Superior," *NASA*Available: https://www.jpl.nasa.gov/news/news.php?feature=6680.

[9] Howell, E., "Parachutes, Sky Cranes and More: 5 Ways to Land On Mars," *Space.com*Available: https://www.space.com/33483-mars-landing-technology-viking-curiosity-rover.html.

14. Appendix

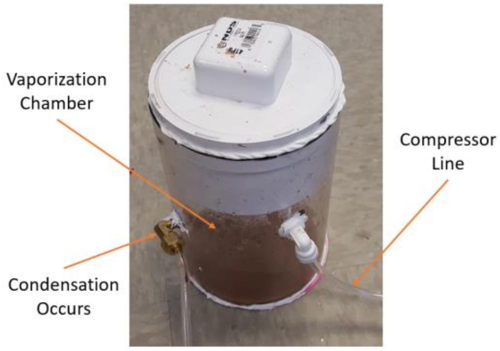

Figure 17. Water-Vapor Condensation Prototype.