ICICLE

Ice Core Integrated Calescent Linear Extractor

Cornell University
College of Engineering

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Challenge: Micro-g NExT – Surface Sampling Device

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A. Abstract

As the human population continues to rise at exponential rates, increased research efforts aim to address the future of extraterrestrial habitation for mankind. Among the most auspicious candidates for our extraterrestrial migration are "Ocean Worlds," moons in our Solar System that meet the most austere requirements for human habitation. Surface temperature, atmospheric composition, and accessibility to potable water are a few of the most fundamental criteria when evaluating extraterrestrial bodies for living. Water, so far discovered in its solid, liquid, and gaseous forms, has proven to be abundant among the planets in our Solar System (and Pluto). In September of 2015, existence of water on Mars was publicly confirmed by The National Aeronautics and Space Administration (NASA) [1]. Albeit the only signs of water are long streaks of dark sand, the mere discovery of water on Mars boosts the chances of future habitation. Other extraterrestrial bodies in our System that show signs of water (or ice) are comets, moons, planets and dwarf planets such as Temple 1, Europa, Neptune, Enceladus and Pluto.

Europa is a particularly intriguing candidate that has been recently scrutinized. It is one of Jupiter's moons, sized slightly smaller than Earth's moon, primarily composed of silicate rock and believed to boast an under-surface ocean comprised primarily of liquid water. This ocean, hypothesized to be a result of tidal flexing caused by Europa's eccentric orbit, is one of the prime candidates in the Solar System for extraterrestrial life due to the presence of reduced oxidant species and the necessary elements for life as we know it [2]. NASA currently has plans to send a mission to the Jupiter system, the Europa Clipper, to conduct flybys of Europa to study its habitability and to scout locations for landing a rover to conduct chemical analysis on samples of the Europa surface [3]. Proposals for future missions to Europa include sending a subsurface rover to directly study the ocean underneath its ice crust. Part of this rover's mission would involve taking stratigraphic samples of ice. These samples, possibly containing un-fragmented signs of life, would catalyze unprecedented research about the environmental conditions on this moon and how they have developed. Not only would the composition of Europa's water be evaluated but also, potentially undiscovered bacteria or microorganisms found in these ice samples could radically broaden our understanding of extraterrestrial life and the origin of life here on Earth.

Under NASA's Micro-G NExT competition, academic research teams are tasked with the challenge of proposing an Under-Ice Sampling Device. This device would be a module in a submersible rover, launched and flown from Earth to an Ocean World's surface. This ice sampling device would operate under simulated Ocean World terrain (i.e. water and ice), and attempt to collect an uncontaminated and sample of ice. Once collected, this ice sample would remain uncontaminated until it is retrieved and analyzed by researchers back to earth. The following document proposes a design by Cornell University's Micro-g Project Team for an Under-Ice Sampling Device.

B. Design Description

1. Technical Design

The team's primary focus in the design of ICICLE was simplicity of the tool's design and reliability in its function. The team sought to find a design that met the volumetric requirement for sample retrieval while ensuring the ICICLE would interface seamlessly with the Mars Buoyant Rover and collect the desired sample under ice. ICICLE takes an input of 12V to actuate and heat a thermal drill which retrieves cylindrical ice samples of NASA's specified dimensions. The thermal drill allows for optimal under ice sample retrieval with a minimal administered buoyant force due to the efficiency of the thermal collection method. A full CAD rendering of ICICLE is shown below with the naming convention for each component.

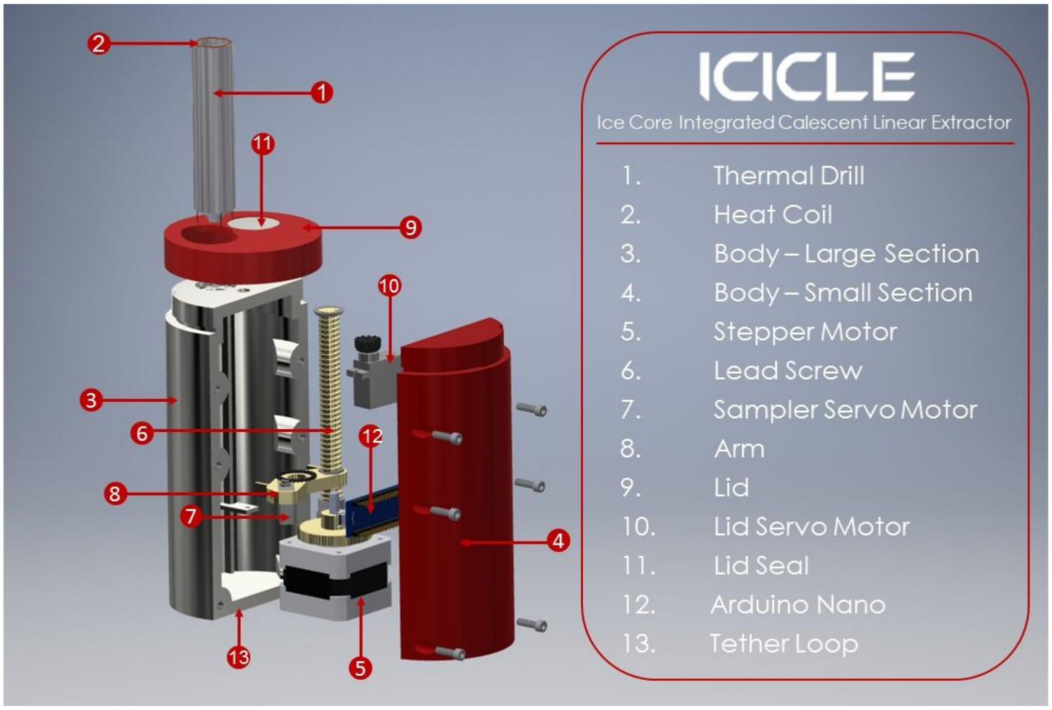

Figure 1: ICICLE Exploded View

1.1 Lead Screw Actuation

The thermal drill moves along a vertical axis, actuated by a linear actuator composed of a lead screw and threaded nut. The linear actuator was designed to be axially offset from the thermal drill, as their combined length exceeds the given length constraint (6"). An offset linear actuator allows sufficient space for sample collection, movement, and storage within given constraints while simultaneously providing space for motors, wiring, and other electronics. A stepper motor spins the lead screw which causes the threaded nut to rise and fall depending on the direction of spin. The threaded nut is connected to the arm, on which the thermal drill is fixed through a bearing. Due to this configuration, the turning of the lead screw will cause linear motion of the thermal drill, creating the movement needed to collect an ice sample. The motor and arm are mechanically fixed to the body such that neither part rotates relative to the device. The rising nut pushes the platform and thermal drill upward and out of ICICLE. Once collection is complete, the thermal drill is retracted by spinning the threaded nut in the opposite direction, linearly pulling the thermal drill and its platform back into ICICLE.

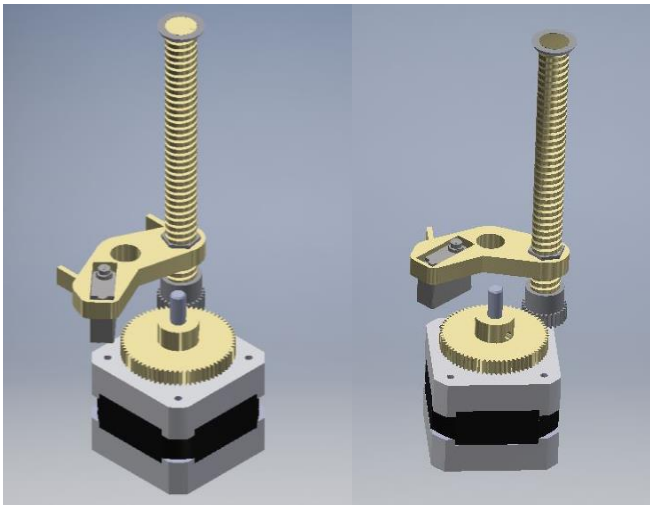

Figure 2: Isometric view (left) and side view (right) of actuator

1.2 Lid

The lid of the device serves primarily to expose the thermal drill immediately prior to collection and seal it within the tool once it has retrieved a sample. Before sample retrieval, the lid is rotated to the position such by a servo driven axle through its center. A gear-to-gear interface between the servo and lid's axle drives the lid's full range of motion without interfering with the path of the thermal drill. In the open position, the thermal drill is directly below an extrusion through which it can freely protract. Once collection is complete and the sample has been brought into the tool, the lid returns to its closed position in which the thermal drill and sample are sealed by a stopper-like extrusion built into the lid which will be separately manufactured. Additionally, the lid has a stopper-like extrusion to seal the thermal drill. More detail on sealing the thermal drill with the lid is described in the following sections.

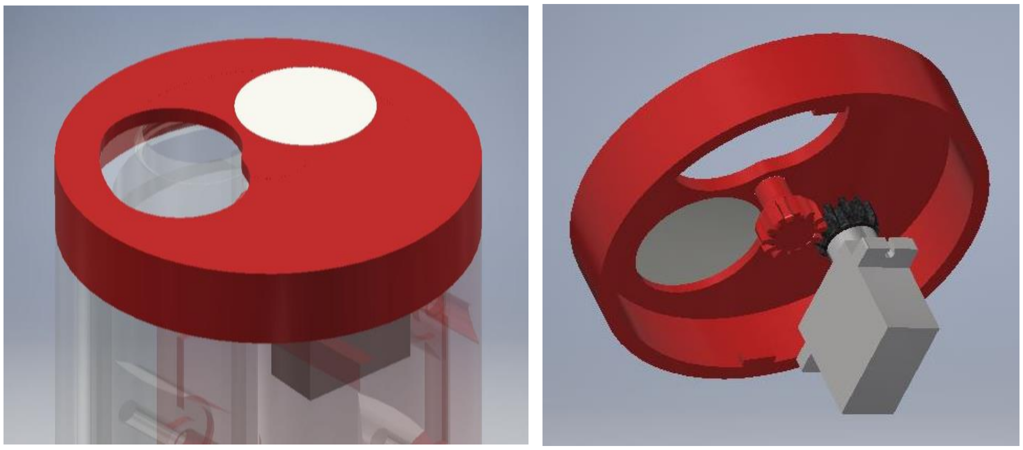

Figure 3: Top view (left) and bottom view (right) of ICICLE lid

1.3 Sampling Mechanism

ICICLE's sampling mechanism consists a thermal drill, designed to satisfy the sample collecting constraints of this challenge. The drill is a cylindrical hollow tube that uses resistive heating to cut through the ice. The top inch of the drill is heated by nichrome wires wrapped around a ceramic tube housed in a thermally conductive metal tubing. For collection, the tip of the thermal drill is pushed into the block of ice to be sampled. The top surface of the drill consists of nichrome wires housed in an octagonal configuration embedded into the top face of the drill which sever the ice sample from the surface after the drill has penetrated 3" into the surface. After a complete 3" extension, the thermal drill is rotated 90° by means of a servo connected at its base. This rotation causes the wire at the face of the drill to become taut and travel to the center of the drill, severing the sample from the block of ice. After it has retrieved the sample, the thermal drill is retracted back into ICICLE. The wires remain interlocked at the tip of the drill to keep the collected sample inside the thermal drill. Once the thermal drill is fully retracted and the lid closes and the drill is again pushed upwards towards the closed lid. A stopper in the lid, above the thermal drill, fully seals the sample inside the drill.

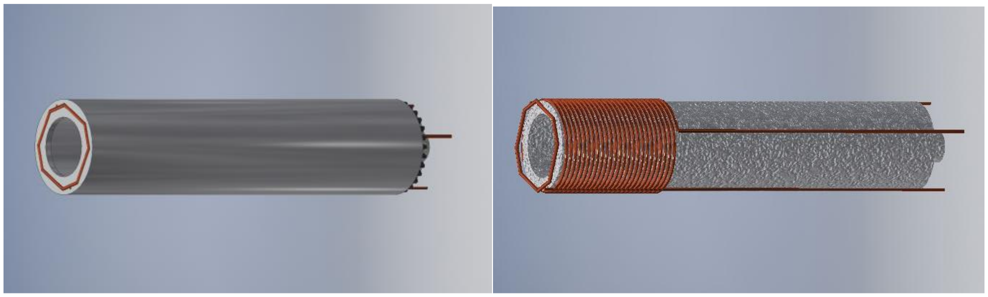

Figure 4: Thermal drill isometric view (left) and internal view (right)

1.4 Body

The overall shape of the body of the tool is a 3D printed cylinder 3 inches in diameter and 6 inches long, as specified by the challenge requirements. This ensures the tool will seamlessly interface with the buoyant rover, while maximizing room for internal components

The main design considerations are waterproofing and an accessible interior for the repair and adjustment of the interior assembly. Accessibility of internal assemblies is ensured through the strategic cut through the body of the tool separating it into two parts. The cylinder is cut 0.35 inches from the center of the device, opposite the side of the thermal drill. This dimension was selected to allow for easier waterproofing, without cutting through the areas of the tool that house the axle and drill. The body is comprised of two housing sections to be fastened by bolts through threaded holes on the outside of the body. There will be 3 pairs of threaded inserts and bolts on each side of the cylindrical housing to clamp the two bodies together. The body will contain features for housing other components of the tool – grooves for the actuation arm, mounts for the motors and Arduino and a retractable tether loop.

For this device to be completely submerged underwater without damage to the interior components, the edge of the body will be sealed by an O-ring, which is water, steam and heat resistant. [5] The connection between the body and lid axle will also be sealed with an O-ring.

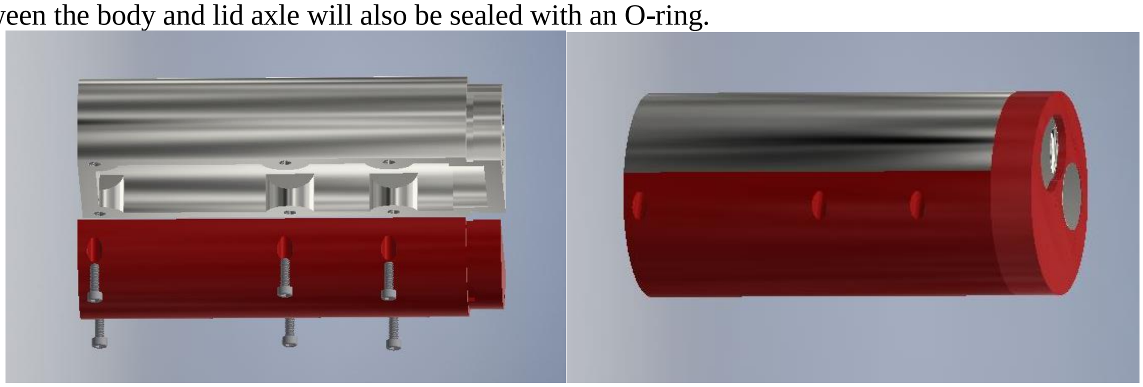

Figure 5: Exploded view (left) and side view (right) of body

1.5 Electronics

A significant amount of functionality of the tool is based upon electronically driven components that must be operated asynchronously. As such, the two main electronic aspects consist of power distribution to each of the components as well as individual control via a microcontroller.

To prevent water damage of the electrical assembly, ICICLE employs water, steam, and heat resistant O-rings which ensure that any breach points have been made watertight. Additionally, all electrical connections will be sealed with NBL approved silicon to avoid electrical shorting. Finally, the main external electrical connection, consisting of power and UART, will be made using an automotive-grade waterproof connector, whose female counterpart will have long extensions to be wired to NASA's power supply and control equipment.

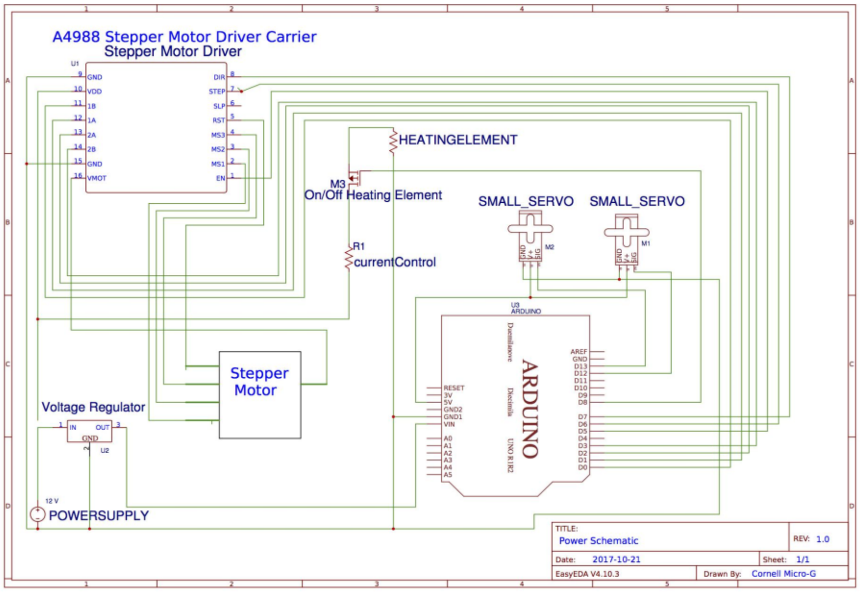

Figure 6: Wiring for Electrical Components

The voltage regulator allows for the supply voltage to be reduced from 12V to a manageable 9V operating value for the Arduino. The servos will be driven from the Arduino because of their operational power requirement (from the 5V pin). The control commands for the servos will be given by the Arduino (pins D13 and D12), which will determine which position to set each to. The command and actual control protocols of the servos is discussed in the next paragraph. The stepper motor requires a driver chip to function. Pins on the Arduino will send commands (D0 to D3 and D5 to D7) to the appropriate pins on the driver chip (pins 1A, 1B, 2A, 2B, STEP, DIR, and EN) to provide the functionality discussed later. The powering of the stepper motor will be through the driver chip; the motor is rated for 12V and thus, the power supplied to the driver chip will be directly from the 12V power supply. The heating element itself is essentially a resistor that will supply heat as it consumes power. A metal oxide semiconductor field effect transistor (MOSFET) will be implemented to supply current to the heating element at the appropriate time. If the signal to the MOSFET is high, it will allow current to flow to the element. If the signal sent to it is low, it will close the MOSFET and stop the element from heating. The functionality is essential to keep the thermal drill from melting other aspects of the tool in the stored position as well as preventing it from melting the sample after collection. Power calculations are shown below in Table 1 showing that each element will fit within the given power constraints.

Table I: Current Draw and Power Consumption

Component	**Current Draw (Max) (A)**	**Power Consumption (Max) (W)**
Arduino	.34	3.06
Servos	1.56	7.8
Stepper Motor	.33	3.96
Heating Element	8	96
TOTAL	10.23	110.82

The tool's maximum power consumption totals to 110.82W, which is well below 300W, the maximum power rating of the NBL power supply. The tool will be supplied 12V, allowing up to 25A of current draw to the tool. The tool's maximum current draw of 10.23A is well below the maximum current the power supply provides. The currents in the Table I assume maximum current draw, meaning stall current in the case of actuators, steady-state current in the case of the heating element, and full GPIO usage in the case of the Arduino.

The Arduino will precisely control and regulate the servos and stepper in order to ensure successful sample collection. Without such precision, the lid may obstruct the thermal drill, the drill may not extend fully, and the heating element may not be administered proper power. The commands going to the stepper motor will first be run through the stepper driver, which translates the signals to precisely actuate the stepper given the external power input.

A single Arduino sketch will control the timing and actuation of all subsystems. The code shown in Figure 7 will open the lid with a 105-degree rotation, actuate the thermal drill forwards and back, and the close the lid again. This code serves as a basic template to expand upon.

```
#include <Stepper.h>
#include <Servo.h>
//Initialize pin connections, depending on motor wiring
const int Pin1 = 1; const int Pin2 = 2; const int Pin3 = 3; const int Pin4 = 4;
const int Pin5 = 5;
const int stepsPerRevolution = 100; //depends on stepper motor specifications
int pos = 0;          //servo initial position
Stepper stepMotor = Stepper(stepsPerRevolution, Pin1,Pin2,Pin3,Pin4);
Servo servoMotor;
int motorSpeed = 60;  //Set motor speed value for actuation in rotations per minute (rpm)
int rotationNum = 5;  //number of rotations needed for actuation
boolean command = true;
void setup() {
  stepMotor.setSpeed(motorSpeed);
}
void loop() {
        while (command){  //open the lid using the servo motor
              for(pos=0;pos<=90;pos+=1){
              servoMotor.write(pos);
              delay(15);
              }
        //actuate the drill (forward and back)
        stepMotor.step(rotationNum);  delay(1000);
        stepMotor.step(-rotationNum); delay(1000);
              //close the lid
              for(pos;pos>=0;pos-=1){
              servoMotor.write(pos);  delay(15);
              }
command = false; //actuation motion complete
        }
}
```

Figure 7: Computer Code for Arduino Generated Commands

2. Manufacturing Plan

The different components of ICICLE will be machined, 3D-printed or constructed using stock materials from McMaster-Carr or Grainger. [6] The motor, Arduinos, stepper drivers, and wiring will mainly be purchased from Adafruit.com along with several other websites outlined in the bill of materials. The body and the lid will be 3D-printed using translucent, high-strength PETG material using the additive manufacturing facilities in Cornell’s Rapid Prototyping Lab (RPL). All aluminum machined parts will be made in Cornell’s Emerson Machine Shop using manual lathes and mills. Once the necessary materials have been obtained and parts have been prepared, the ICICLE team members will assemble the tool’s components into the final production.

Table II: Design Compliance Matrix for Under Ice Sampling Device

Requirement	**Compliance**
The device shall collect cylindrical samples 0.5” in diameter and 3” deep	As validated in section B 1.1, the sampling mechanism will collect a cylindrical sample 0.5” in diameter and 3” deep.
The device shall collect, seal, and store at least 1 sample	As seen in Figure 1, the device shall collect, seal, and store 1 sample.
The device shall obtain a subsurface sample from solid and slushy ice	As validated in section D 3.2, the sampling mechanism shall obtain a subsurface sample from solid and slushy ice.
The device shall minimize cross contamination between samples	The collection and storage of the samples is completely separate as the tool only collects one sample.
The device shall minimize contamination by air and water once obtained	As seen in Figure 5, the device is sealed so there will be no contamination by air or water once obtained.
The device can be operated electrically by no more than 12V. Power to be supplied by NBL only	As described in section B 1.5, the device is designed to take in a voltage of 12 Volts.
The device can have multiple parts that can attach and detach	As seen in Figure 1, the device is comprised of multiple detachable parts.
The device (all parts, in stowed configuration), shall fit within 3” diameter and 6” cylinder	As seen in Figure 1, the device has a 3” diameter and 6” cylinder.
The device (all parts) shall operate underwater with provided electrical power	As described in section D 3.2, extensive testing will be done to ensure ICICLE’s functionality underwater.
The device (all parts) shall have a dry weight of less than 5 lbs	The predicted weight of our device is 2.67 lbs.
The device shall be commanded via general purpose input/output lines (3.3V or 5V compatible), or via a Universal Asynchronous Receiver / Transmitter (UART – 3.3V / 5V).	The device will be run off of an Arduino which implements the use of Universal Asynchronous Receiver/ Transmitter.
The device shall be compatible with a chlorine water environment and a saltwater environment	The device will limit its exposure of the chlorine/salt water to only the top of the device and around the sampler and outer body which are resistant to salt and chlorine. The rest of the tool will be water resistant.
The device shall operate within an environment from -5° C to 30° C.	All component materials delineated in Table V are confirmed to behave normally within the given temperature range.

C. Operations Plan

1. Procedure

The following procedure explains how ICICLE will collect samples of the given dimensions in a chlorine or saltwater environment. The necessary pre-test preparations are delineated below assuming ICICLE has been properly connected to both the UART communication cable and the power supply lines.

1. ICICLE will be secured on the NBL test platform positioned underneath the ice and administered 10 lbf of buoyancy by an NBL certified diver.
2. ICICLE's lid will then turn and expose the sampling mechanism to the water.
3. After the sampling mechanism has been given time to heat up, the mechanism will extend into the ice. The ice will melt around the mechanism allowing it to take a core sample.
4. After the mechanism has extended to at least three inches into the ice, two curved sections of wire at the leading edge of the sampler will straighten, extending from the walls to cut the ice core. The wires will remain in the middle of the core sample to aid in the collection of the core.
5. The sampling mechanism with the captured ice core will retract back into the tool.
6. After retracting past the lid, the lid will turn to its initial closed position
7. The sampling mechanism will rise into the grooves of the lid, sealing off the sample from the environment.
8. Retrieve ICICLE to obtain the sample. Repeat the testing process to obtain additional samples

2. Expected Experimental Data

Testing conducted at the NBL will provide important data for evaluating the viability of a melting-based collection cylinder for the collection of ice cores from ice beds on Europa as well as other celestial bodies. The NBL testing site serves as a useful space analog for the testing of the device's reliability, usability, and functionality. The decisive measure of success will be whether the device has collected an ice core sample of approximate diameter 0.5" and approximate length 3". In evaluating the success of the tool, several factors pertaining to ICICLE's performance will be considered. We define these parameters as sample geometry, sample stratigraphy, and total time for sample collection and retrieval. All data obtained during the testing phase at Cornell will be logged for comparison with data obtained during test week at the NBL.

D. Safety

1. NBL Engineering and Safety Requirements

Table III: NBL Engineering and Safety Requirements for Tools

Requirement	Compliance
All tools must have a tether loop which will allow the astronaut to use a tether with hooks (similar to a carabiner hook) to restrain the tool.	As seen in Figure 1, the tether is included on ICICLE so that the astronaut can easily attach the device to the given platform.
All tools must be operable with EVA gloved hands (like heavy ski gloves).	The device only needs to be manually operated with EVA gloved hands for its set up on the test platform. Such operations are easily completed with gloved hands.
Tools must not have holes or openings which would allow/cause entrapment of fingers	The tool has been designed such that the main opening for the thermal drill will be closed by the lid when being handled by the astronaut. Only after the tool has been properly installed in the test platform will the opening be exposed. There are no other holes or openings which would allow entrapment of fingers.
All pressure systems shall be constructed from COTS components that are rated for the maximum operating pressure OR comply with ASME standards. Unique components not covered by the ASME standards shall be designed to a Factor of Safety of 4 to burst and complete stress analysis reports for those	The tool does not include any pressurized systems.

components shall be required.	
Hydraulic Power Requirements	The tool does not use hydraulic power.
Pneumatic Power Requirements	The tool does not use pneumatic power.
Electrical Power	The tool has been designed to intake a voltage of 12 volts to run the electronics of the system. The inside of the tool will be waterproofed using O-ring seals and rubber gaskets. All electronics will be coated with silicone sealant inside the waterproofed tool and not be exposed to water. IP-67 rated electrical connectors will be used to avoid shorting. As a final precaution, all electrical connections inside the tool will be insulated using NBL approved silicone rubber adhesive sealant.
The tool must be able to survive in water that contains a range of 0.5 to 3.5 parts per million of free chlorine.	This range of chlorine will have no adverse effects on the tool given the material choices delineated in the bill of materials.
The tool must be operable in a temperature range of +82° F (27.8° C) to +88° F (31.1° C).	The materials of ICICLE delineated in the Table V can function within the given temperature range.
The tool must be able to withstand a depth of 40 feet.	As seen in the FEA in Figure 9 and in Section D 3.2, the tool will be able to withstand a depth of 40 feet.
The tool must be constructed using acceptable materials for use in the NBL.	As seen in Table V, the tool uses only materials explicitly stated to be acceptable for the NBL.
Because of the potential for personal injury to diving support personnel and damage to the EVA suit, the mockup components shall not contain sharp edges and items capable of cutting or puncturing items coming into contact with them.	As seen in Figure 1 The tool does not contain any external sharp edges. All components will be printed or machined to have rounded edges for maximum safety.
Operators must be protected from pinch points and/or sharp edges.	The tool has no sharp edges or pinch points on the exterior body.
The hardware shall be designed to specify manufacturing to remove burrs, break all sharp edges and round all corners.	The hardware for ICICLE will be designed and manufactured to remove burrs, break all sharp edges, and will only have rounded corners. All machined parts will be post-processed by deburring or sanding all edges and corners.
Mockups and hardware shall be designed with drain holes or geometry to allow the free flow of air and water as required to support submersion and removal to and from the NBL pool.	The inside of the tool will be waterproofed using O-ring seals and rubber gaskets. Because no water will enter the tool, there is no need for drain holes.
The hardware provided shall have labels as follows: Mate/de-mate alignment marks, operation indicators, as required; caution and warning tags for Hazard areas (i.e., pinch points, sharp edges, etc.); hardware identification, and any additional labels requested by Test Readiness Review (TRR).	Labels marking hazardous areas of the tool will be added during fabrication. Guidance will be solicited from NBL contacts on any additional safety labels required.
The hardware must withstand normal handling or kick loads and not present a safety hazard	Special care has been taken throughout the structural design and material selection process to ensure that the tool can withstand normal handling loads.

2. NASA EVA Safety Requirements

Table IV: Design Compliance Matrix for NASA EVA Safety Requirements

Requirement	Compliance
Temperature	The heat produced by the tool will not affect the overall touch-temperature limits on the device's body due to thermal isolation of the heating element.
Radiation	The tool does not emit radiation, nor does it shield the operator from radiation.
Micrometeoroids and Debris	Not applicable
Chemical Contamination	The tool design does not include any hazardous chemicals.
Edges and Protrusions	The tool has been designed without any external sharp edges or protrusions to prevent puncturing or otherwise damaging other EVA equipment.
Hazardous Equipment	The tool's sampler produces heat but will be stowed away when not in use, ensuring operator safety when mounting and dismounting the tool.
Ingress/Egress	As seen in Figure 1 the tool fits within the size constraints of the challenge, and should fit easily through any ingress/egress hatch.
Power Sources	The tool will run solely on the power included for us by NASA. The tool will not produce its own power.
Transmitters	The tool does not contain any transmitters.
Tethers	The tool has a tether to which the astronaut can easily connect.
Ignition Sources	Not applicable.
Positive Pressure	The tool will not emit pressure, nor does it shield the operator.
Electrical Voltage	The tool will not produce electric shocks to the astronaut, and electric circuits will be properly connected to ground.

3. Test Description

3.1 Background

To test ICICLE's objective functions and ensure its structural integrity during collection, test conditions must simulate significant aspects of the challenge environment. Our tool is expected to operate while completely submerged in waters with temperatures ranging from $-5°$C to $30°$C, as well as a pressure of 2.2 atm. The following measures are designed to ensure ICICLE can complete its mission without damage to itself or those handling it during operation.

3.2 Design Validation

The team has conducted preliminary testing to validate our design choices and will continue to perform extensive testing of ICICLE throughout the fabrication process. Multiple iterations of physical prototypes were constructed to validate an optimized relationship between current draw and drill geometry. The dimensions of the thermal drill were determined to be 0.8" outer diameter and 0.5" inner diameter with the heating element of the thermal drill drawing a maximum of eight amps. Necessary calculations were performed to determine the length of wire needed for resistance heating. Using the heat of fusion of ice, current of 5A, and a melt time of 30 seconds, we determined that approximately 7Ω of resistance were needed, which was confirmed by testing, as shown in Figure 8.

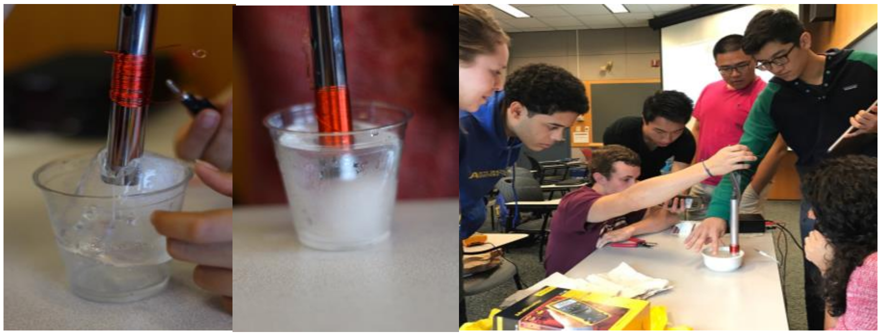

Figure 8: Thermal Drill Prototype and Design Validation

Future validations will be conducted to test improvements on the heating element and sample retrieval mechanism. Switching to a higher resistance wire will require shorter wire and less time to melt the sample. We will be testing 38 gage nichrome wire of length of ten inches for resistance heating with a factor of safety of three.

Finite element analysis (FEA) using ANSYS confirms the ability of the body container to withstand 2.2 atm of pressure as required by the NBL. As shown in Figure 9, the body of ICICLE has an equivalent stress safety factor of a minimum of 5. This validates that the body of the tool will not fail due to the hydrostatic pressure of the NBL. Additional FEA was conducted in order to verify that no major deformation of the tool will occur due to the pressure in the NBL which would prevent the actuation of the thermal drill.

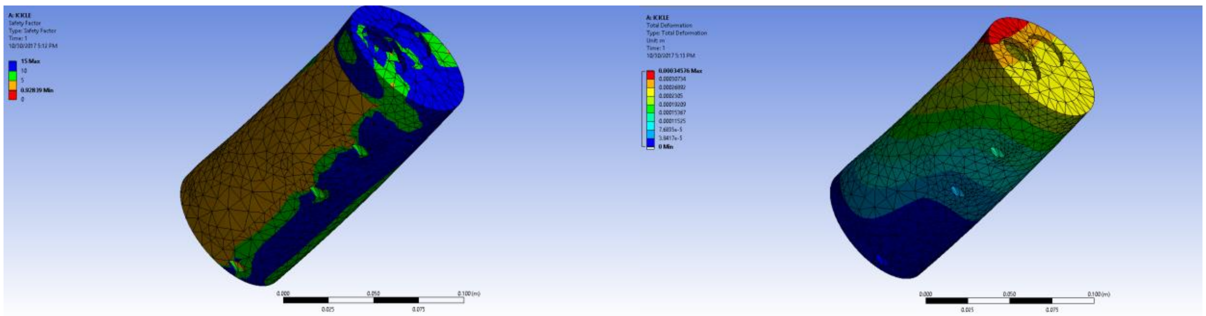

Figure 9: Factor of Safety in Stress and Deformation for ICICLE due to NBL Pressure

The electronics assembly will be tested first above water to ensure the functionality of ICICLE's motors, servos, and steppers in an environment which supplies identical power to the NBL. Each electrical component will be tested individually as well as in conjunction with the entire electronics assembly. The voltage and current that each component draws will be confirmed during testing. Once the functionality of the electronics assembly is confirmed, the lid and thermal drill actuation will be tested until they are able to achieve sample collection both above water and submerged.

To ensure the ability of ICICLE's electronics assembly to function in an underwater environment, the waterproof seal and silicone sealant need to be tested. To test the watertight seal, the empty device container will be submerged completely underwater, after which the team will examine if any water entered the chamber. The efficacy of the hydrophobic silicone sealant will be verified by submerging an individual component in water once it has been coated.

The final validation of the design before testing week at JSC will take place at the Helen Newman pool at Cornell University. At least one SCUBA licensed subject will prepare a test of the finalized unit underwater. The tool diver will mount the tool on a platform, which will model the Buoyant Rover inspired-platform that will be used for testing at the NBL. The SCUBA license operator will connect appropriate input cable to the tool. After this, the diver's interaction with the tool will cease until the test is complete. A block of ice which is at least large enough to contain a 1' cube will be used as the sample bed. The sample bed will be attached to a simple truss mechanism that will be weighted down such that the tool can collect ice from underneath the test bed. The watertight seals are expected to be able to withstand pressures multiple times larger than those that will be encountered at the NBL. Testing at the Helen Newman pool will confirm the tool's ability to operate in a chlorinated water environment. Quantitative data regarding the time required for the collection process and the dimensions of the collected sample, as well as qualitative data such as the shape and structural and stratigraphically integrity of the collected sample, will be collected.

3.3 Failure Modes

Failure of the tool can occur at any point of stress on the tool due to internal mechanism failure or outside stress. Because electronics are involved, isolating the electronic systems from failure points is important. Failures which cause water to flood the watertight sections of the tool are the most critical, since they threaten the functionality of the electronic components. However, as described in the above sections, extensive testing and design focus have gone into ensuring the device is waterproof   Choosing well-connected and strong components to transfer power from the motors to the linear actuation of the drill or to open the lid should eliminate the possibility of disconnection or loss of mechanical power. Not securing connection to the motors themselves from the power source and microcontroller could possibly cause a loss of electrical power. Should either of these failures occur, the drill and actuation motions will not operate correctly, though the tool will remain sealed and safe, capable of being retrieved and fixed.

4. Ground Support Requirements

In case parts are damaged during transit from Cornell, the team will bring a standard engineering toolkit to execute repairs. The team will bring an electrical toolkit containing a spare servo, stepper actuators, a spare pre-programmed microcontroller, wire, wire cutters, and NBL approved silicone rubber adhesive sealant. The team will also bring multiple thermal drills, screws, O-rings, and fasteners. The team does not anticipate requiring any additional assistance for repairs from the NBL staff on site during test week.

5. Test Equipment Data Plan (TEDP) Compliance

The Cornell Microgravity Project Team will submit a full TEDP document at least 8 weeks prior to testing at the NBL. This document will provide a more detailed safety analysis of the final design than is presented in this proposal.

E. Technical References

1 Anderson, G. (2015). NASA Confirms Evidence That Liquid Water Flows on Today's Mars. [online] NASA.gov. Available at: https://www.nasa.gov/press-release/nasa-confirms-evidence-that-liquid-water-flows-on-today-s-mars [Accessed 28 Oct. 2017].

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4 Joe Souney, U. (2017). Thermal Drill : U.S. Ice Drilling Program. [online] Icedrill.org. Available at: http://icedrill.org/equipment/electrothermal.shtml [Accessed 28 Oct. 2017].

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III. Outreach Plan

A. Objective

Inspiring the next generation of NASA engineers and scientists is as an indispensable part of the Micro-g NExT competition, as designing and developing the tool. The team is focused on stimulating interest and involvement in NASA, space exploration, STEM, and current events involving space technology advancement. The team's target communities are Cornell University, Tompkins County, and the followers we are able to reach via social media. We will interact with these communities by working with organizations within the university, local schools and organizations, and a broad student base on the internet. The team is focused on beginning outreach work and becoming engaged with students.

The team has three main outreach objectives: introducing and developing scientific knowledge, providing appropriate explanations and information, and inspiring the new generation of scientists and astronauts. The first goal is centered around exposing as many students as possible to the work being done by our team and NASA and to the endless possibilities students may have in pursuing and participating in science fields. The team will do this by reaching a multitude of bases, both sharing experiences and providing activities and events to the community. The team will make it a priority to show that people of any gender, race, background, age can be involved in STEM and space exploration. The second goal is centered around tailoring our information and events to our specific audiences and making sure every student is engaged and understanding the material. Our vision is to create an understanding between our team and the audience. The team aims to benefit every student by creating age appropriate activities and lectures that both illuminate interesting topics of space and also provide key information about those topics. Finally, the third goal will be achieved by guiding students into the future, and developing them into the next generation of scientists, engineers, and space explorers. By informing students on recent discoveries and developments in space we want to prompt them to imagine themselves as astronauts or scientists. The team will be interacting primarily with students in grades 5 through 12, a key age in educational development, and will encourage students to either take on a new interest in science or pursue a current one.

B. Audience and Channels

1. Cornell University

Cornell University fully supports the space research community and houses multiple academic departments devoted to expanding space-related knowledge. Cornell also highly encourages independent research and exploration within these departments, and has expanded its relationship with space exploration by founding the Carl Sagan Institute in 2014. This institute was founded to continue the work of Carl Sagan, a previous member of the Cornell faculty, for the search of life outside of Earth. With these opportunities at Cornell, the university has surely reached beyond the Micro-G NExT competition to stimulate the interest and passion of undergraduates for space-related opportunities.

Our team at Cornell specifically plans to involve the undergraduate community to help further push towards the future of space-related research and exploration. This year, we will be partnering with other space-related clubs to host campus wide events. We have already reached out to Cornell Astronomical Society, to co-host events for undergraduates such as rockets and demonstration on Cornell's arts quad, and telescope viewings and demonstrations at Fuertes Observatory, Cornell's on-campus observatory Specifically, in working with the many departments in Cornell such as the Mechanical and Aerospace, Astronomy, Physics, and the Earth and Atmospheric Science departments our team wants to educate undergraduates on the opportunities in microgravity research and our engagement with NASA.

Additionally, Cornell Micro-g will showcase ICICLE, as well as our past tools at these events, and explain the design process behind it.

Our involvement within the undergraduate community at Cornell, will encourage more students to form a passion and support for microgravity research. This encouragement will highlight the campus-wide commitment to NASA's mission of engaging the next generation of scientists.

2. Local Community

As part of our mission to reach a large demographic of people, we plan to connect with the local Ithaca community. This year, the Cornell Micro-G team will be visiting museums, elementary, middle, and high school students to spark an interest in space-related fields. We will be reaching students at an important age, where we feel we can influence and inspire them. By introducing concepts like space exploration, the Micro-G NExT competition, and the engineering design process, we hope to spark an interest that can grow and develop in the future. Furthermore, by going to high schools, we are targeting kids in a later stage of their life, where they are beginning to look towards their future and how they want to impact the world. We hope to introduce areas within STEM that are potential career paths for the students. We hope our hands-on approach will engage and interest the students in these areas of study.
Likewise, we will host events at museums and centers, such as the Ithaca Science Center. Presenting at family-friendly organizations, will allow us to have a broad audience. Working with the local community excites Cornell Micro-G, and we cannot wait to bring our interest of space to those around us.

3.Social Media

Social media will be an integral part in our means of communicating with our community about the Micro-G NExT Competition, current space related news, and our very own project. Our team will be using several different platforms including, Facebook, Instagram, and Twitter.

Our Facebook page will allow us to connect with a wide-range of individuals, and showcase updates about the progress our team is making. Facebook will allow the team to spread word about events that will be held to increase the public's attention to space-related news. Additionally, we will allow any team member to post updates or pictures, providing relevant date information about our team's progress.

Secondly, Instagram will be used to show a more direct look into our progress of the tool, through the use of photos showcasing sketches and designs of the tool, and all the steps between the start of our process and the final product. Furthermore, we will also use videos that will include team members explaining what about space excites them, why they joined the team, and the specific components they worked on.

Twitter will be our team's most prominent way of communicating information. Through twitter we will tweet pictures and updates, Twitter will be used in a more immediate and concise manner. The team will also tweet enticing space facts and links to news article about space advancements. Finally, to fully engage with the public there will be opportunities for the public to be invited to tweet questions about our project, NASA, or any space-related information to our account, and we will respond in real time. Overall, social media will play a big role in interacting with people of all different backgrounds even outside of our geographical region.

4. Website

This year, our team has made a new website: https://cornellmicrog.wixsite.com/cornellmicro-g. It will also be a comprehensive base to outline the progress and details of our tool. By using Cornell Micro-G website, we are looking to link our social media presence to a platform that can better inform the public about our efforts. Important elements of the website will include information about our team's mission, details of our design progress, our partnership with NASA, contact information of team members, and former and upcoming events. Presenting our team's mission, we will include why the team is passionate about this project, and our interest in space exploration. In addition, we will also include our interaction with NASA and all the opportunities this has opened for us as students interested in space exploration. We will be posting updates and pictures of our latest tools designs and prototypes when they are manufactured. In doing this, we are aiming to create a space that will allow the public to see what we have been working on in detail, better allowing us to interface with the public about our ideas and designs for space tools. Lastly, our website will show our past and future events. These events will show all events we are hosting, this can include engagement with local schools, events hosted within the local community, workshops developed to display our prototypes, and or seminars that will show the latest in space exploration. We are posting all our events to show our interaction with our local community and hopefully allowing us to reach more people, get them involved and increase enthusiasm that surrounds space exploration.

5. Local News

Furthermore, we are taking a new approach this year by working with local new sources in the Cornell and Ithaca community such as; Cornell Daily Sun, Cornell Radio, Ithaca Journal, to not only increase our presence in the community, but also reach other audiences that use more traditional news sources. Through the Cornell Daily Sun and Ithaca Journal we will be presenting a more summarized goal of our mission, to discuss our partnership with NASA, and our role in the space community at Cornell. We will also use the news sources to advertise events we are hosting to the community. By advertising our mission through more traditional news sources we are hoping to reach older individuals, who may be interested in space also. Along, with the Cornell Daily Sun and Ithaca Journal, we will also use Cornell Radio to advertise our events, and who we are as an organization.

C. Presentation and Activity Plans

For almost all our outreach work, our events will feature two segments, presentation and activity. We aim to provide both relevant and in-depth information as well as hands on experience. To make the most out of each planned activity, our plans will be carried out with varying complexity tailored to the age and level of the student. Not only will it be specific to the grade level it will also be designed to coincide with the national scholastic standards and NASA's 5E model. Specific plans for the activities and how we are going to use the model to structure them are delineated in detail in the sections below corresponding to each age group.

Although the language and complexity of the topics will be different with different groups, the overall subjects and topics will be covered across all channels of outreach, and the hands-on approach will be a prime feature of all activities. The team topics the team will choose to educate the students about include NASA's NBL and its place in space flight development, last year's project and tool featuring demonstrations, basic rocket science and lessons in space environment conditions, and this year's challenge. This year's challenge will provide a great opportunity to teach and instruct about other astronomical bodies in our solar system and beyond, with an emphasis on moons like Jupiter's Europa and the discoveries and science known about it. These goal of our activities is not only to spark interest among students in NASA's work and the broad field of space, but also stimulate valuable thought processes in students, such as problem solving, decision making, and critical reasoning. We aim to provide space-related demonstrations and hands-on activities to demonstrate an application of math and science to realistic situations and the team's end goal is to incite a motivation and excitement for learning new things. These activities correspond directly with the national standards corresponding to K-12 educators. These activities are meant to target, challenge, and allow students to grow in areas such as problem solving and decision-making skills, critical reasoning, developing technical skills, and teamwork and collaboration. Furthermore, these visits to schools are made to show students applications of math and science to real world problems, give students a broader understanding of science in general and how space correlates with current scientific topics, and most importantly, give the students motivation and excitement to learn.

1. Elementary Schools

Our activities for elementary school students will commence at a very introductory level. We assume very little prior knowledge about astronomy, aerospace engineering, and NASA. We will start almost all our events with a multimedia presentation designed for the age group. The NASA 5E Instructional model will be very helpful for this age level. The first step, engage, will be taken on from the onset, as the presentation will help us assess knowledge of the student and pique student interest by providing demonstrations of our past and current tools, showing photos and videos of our tests and trip to the NASA lab, as well as short videos from NASA. At this age level, our goal is to really expose students to new ideas and try to increase interest in space and science at a young age. After the initial presentation, we will continue to explain and extend, by performing hands on activities. One of these activities will involve our tools, this will show the students what they are capable of, inspiring them as well providing tangible evidence. We will present both our tool from last year, our surface sampler, and our current tool ICICLE. The team will explain and demonstrate how the tool works. Each tool is designed for a different environment so we have a variety of tests to do. The students will get a chance to test in a bucket of sand and water to capture soil particles. The students will be asked to reflect on the tasks, and we will explain the many types of astronomical bodies in space, piquing interest in space exploration. Not only will we do these interesting tests, we also want to provide some activities that are fun and amaze the students as at a young age it is important to amaze to garner interest. Model rockets are a fun activity and a great introduction to basic physics. We will allow students to work together to build a prototype safely, and depending on the class age it will be built using straws or a more advanced build for older ages. We want to combine our technical activity with a fun activity so we can evaluate the students in many ways and so we can complete the 5E model.

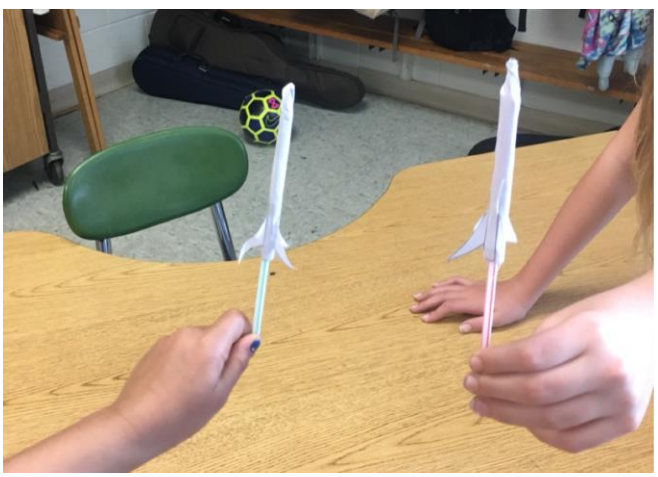


Figure 10: Straw rockets made by elementary school students at Cornell Micro-g's presentation

2. Middle Schools

Similar to elementary school activities, our middle school activities will begin with a basic introduction of the team, the purpose of NASA, and a brief overview of astronomy and the study of physics. This will be on a higher level then what we presented to the younger students. Also, we will present a brief overview of our tools. The technical portion of the visit will focus on some of the themes of this year's tool, like electronic input control and heating. The presenting team members will explain that both in the NBL and in space, divers and astronauts must control rovers and tools remotely and we will show how things can be controlled to perform tasks. Another thing we will focus on is different space environments like the ice surface on Europa. Since technology is more a part of our tool this year, we will incorporate laptop and electronic communication into our activity. Since under ice sampling is another key part we will use both a simulated ice environment as well as others to provide a broad sample of different space environments. One group will use a very basic application we code on the laptop to provide input to the other group who will be the tool or in this case will control the tool. The program on the laptop will be very simple with each key providing a direction or instruction and this group will provide the input to the other group which will follow the input and collect samples from different modeled environments. The goal of this simulation is to show students the difficulty in input control and the constraints of it as well as provide an understanding of the conditions of different environments. The students will be asked to give feedback on how the activity went, if it was successful, and what could be done to fix any flaws. This will introduce students to the engineering design process as well as space technology.

Figure 11: Cornell Micro-g presenting last year's tool, ASTRA, to a middle school class

3. High Schools

While our presentations and activities for younger students are mostly focus on exploring brand new, our outreach activities for high school students will primarily be focused on creative design, and career-oriented activities to inspire students on a more concrete level about space-related research and NASA's professional work. Outreach will involve a mix of interactive and instructional activities to educate students on the different facets of NASA and current space studies. The instructional aspects of the team's outreach activities will primarily focus on future undergraduate engagement with NASA through opportunities like the Micro-g NEXT competition, and potential professional engagement with NASA in STEM related fields. The students will also be introduced to NASA design competitions for high schoolers. As such, the interactive activities will follow a format similar to the format that NASA follows in its undergraduate engagement. High school students will be given a specific task, like constructing a lunar landing module or a space habitat on a hypothetical planet--essentially a task that is relevant to NASA's current needs. They will be asked to break up into teams and create a design and informal proposal. The informal proposal will encourage students not only to think about the technical aspects of the design, but to consider the human factor in their design, and the need to justify their design choices. The design process will be followed by the creation of a physical prototype of their design using rudimentary materials supplied to them, such as paper, cardboard, rubber bands, tape, and other office supplies. In a competition-like format, the prototypes created by students will be tested; for instance, the lunar landing module will be dropped from a height to see if it would withstand simulated landing conditions. The team intends to make high school students aware of the different overlaps between various STEM fields and space-related research, and to focus their scientific interest on the various tasks that NASA currently faces. The teams will then be asked to reevaluate and make changes to their original design. The designs will then be tested again to see if the prototype improved. This will allow for high school students to be exposed to space research as well as the engineering design process.

Figure 12: High school students testing their "Mars Rover" vehicle during a Micro-g event.

IV. Administrative Section

A. Test Week Preference

Test weeks are listed in order of the team's preference below:

Preference 1: 06/04/18 to 06/09/18
Preference 2: 05/21/18 to 05/26/18

B. Mentor Request

The Cornell Microgravity team would be fine to work with any mentor.

C. Institutional Letter of Endorsement

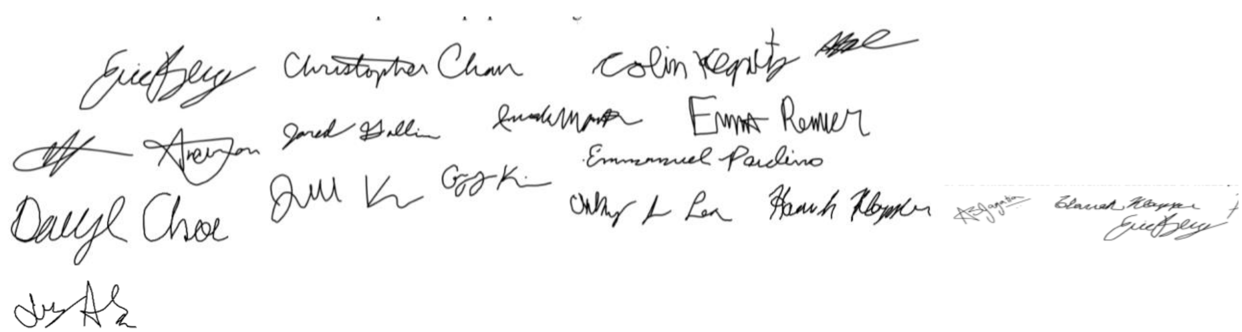
The institution's letter of endorsement is found in Appendix A.

D. Statement of Supervising Faculty

A statement from Ana Diaz Artiles, the supporting faculty member of this team, is found in Appendix A.

E. Statement of Rights of Use

As a team member for a proposal entitled "ICICLE" proposed by a team of undergraduate students from Cornell University, I will and hereby do grant the U.S. Government a royalty-free, nonexclusive and irrevocable license to use, reproduce, distribute (including distribution by transmission) to the public, perform publicly, prepare derivative works, and display publicly, any data contained in this proposal in whole or in part and in any manner for Federal purposes and to have or permit others to do so for Federal purposes only. As a team member for a proposal entitled "ICICLE" proposed by a team of undergraduate students from Cornell University, I will and hereby do grant the U.S. Government a nonexclusive, nontransferable, irrevocable, paid-up license to practice or have practiced for or on behalf of the United States an invention described or made part of this proposal throughout the world.



F. Funding and Budget Statement

Aggregate funding will come from up to fifteen sources. The Bartels Co-Sponsorship, the Space Grant Consortium, the Cornell SAFC Fund, NASA Stipends, and the Cornell Project Team Funding Committee will be the primary sources of funding. The projected cost for travel is $5500 and the material expenses will be up to $500. These funding organizations are all either nonprofits, governmental aggregates, or private companies. The team plans to bring the device with it on the plane to and from Houston, as it is lightweight and well within the domestic carry-on guidelines of major airlines.

A breakdown of the team's estimated costs for hardware design, fabrication and ground testing is given below:

Table V: Equipment and Parts Cost Estimates

Part Name	**Total price**
Body	
Glue	$5.99
Large O-ring	$8.64
Medium O-ring	$3.45
Small O-ring	$1.62
Threaded Inserts	$4.55
Machining	$150
3D printing	$75.00
Electronics	
Stepper Driver	$15.95
Amphenol Waterproof Connector	$14.32
Arduino Nano	$9.95
RTV 108 Silicone Rubber Adhesive Sealant	$9.33
9V Voltage Regulator	$5.45
MOSFET Transistor	$3.53
Thermal Drill	
Epoxy	$16.80
6061 T-6 Aluminum Tube	$6.07
Nichrome wire	$22.25
Servo - Hitec HS-35HD	$24.95
18 Gauge Wire (x10)	$10.60
Nichrome wire (50 feet)	$22.25
Glass-Mica Insulation Rod	$68.57
Actuation	
Nema 17 Stepper Motor	$14.00
Micro Servo	$5.95

Lead Screw Nut	$20.41
Lead Screw	$12.38
Stepper Motor Gear	$2.59
Lead Screw Gear	$3.78
Screw Bearing (x2)	$10.56
TOTAL:	$548.94

The following chart shows the breakdown of travel expenses for six members flying to Houston:

Table VI: Estimated Team Travel Expenses

TRAVEL 2018	
Hotel	$1,800
Flights	$2,400
Car	$600
Food	$750
TOTAL:	$5,550

G. Parental Consent Forms

All team members are 18 years or older, so no parental consent forms are required.

Ithaca City School District, NY

Cayuga Heights Elementary School
110 East Upland Road
Ithaca, NY 14850
Brad C. Pollack, Principal
PH: 607-257-8557
Fax: 607-257-8142

October 20, 2017

We could not pass up the opportunity to have the Cornell Micro-g Team in for a presentation again. Our fourth graders are really looking forward to it. Last year's class thoroughly enjoyed the presentation, as did the teachers and staff. We are very fortunate to have such a learning opportunity at our disposal.

Sincerely,

Erin Hammes, Conor Megivern, and Pam Merola
Fourth Grade Teachers
Cayuga Heights Elementary

1601 N.Cayuga St.

Ithaca, New York 14850

To: Cornell Micro-G Team
From: Todd Crawford
Re: Cornell Micro -G Team
10/29/17

I am very interested in Cornell's Micro-G Team coming to my classroom at Boynton Middle School. Having a program like this offered to middle school students gives them such a great opportunity into real world science application.

Looking forward to hearing back from you to set up a date and time.

Sincerely,

Todd Crawford
6th Grade Teacher
Boynton Middle School

Cornell University
College of Engineering

Sibley School of Mechanical
and Aerospace Engineering

Mark E. Campbell, Ph.D.
John A. Mellowes '60 Professor
S.C. Thomas Sze Director
139 Upson Hall
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October 17, 2017

Micro-g NExT Organizers
NASA Microgravity University Competition
microgravityuniversity.jsc.nasa.gov

Dear Micro-g NExt organizers,

Please accept this letter as acknowledgement of my full knowledge and consent for Professor Ana Diaz's students to participate in the Micro-g NExT Program. Professor Diaz is the instructor of the Cornell course the students are enrolled in which is relevant to the project, and she will also serve as their faculty advisor.

Sincerely,

Mark E. Campbell, Ph.D.
S. C. Thomas Sze Director of the Sibley School of Mechanical
and Aerospace Engineering

\GM

Cornell University
College of Engineering

Sibley School of Mechanical
and Aerospace Engineering

Ana Diaz Artiles Ph.D.
Lecturer & Research Associate
463 Upson Hall
Cornell University
Ithaca, New York 14853-7501
Ph. 607 255-3249
ad877@cornell.edu

October 23rd, 2017

Micro-g NExT Organizers
NASA Microgravity University Competition
microgravityuniversity.jsc.nasa.gov

Dear contest organizer:

Please accept this letter as acknowledgement of my full support for my students to participate in the Micro-g NExT program.

As the faculty advisor for an experiment entitled **"ICICL: Ice Core Integrated Calescent Linear Extractor"** proposed by a team of undergraduate students from Cornell University, I concur with the concepts and methods by which this project will be conducted. I will ensure that all reports and deadlines are completed by the student team members in a timely manner. I understand that any default by this team concerning any Program requirements (including submission of final report materials) could adversely affect selection opportunities of future teams from Cornell University.

Sincerely,

Ana Diaz Artiles
Lecturer & Research Associate
Sibley School of Mechanical and Aerospace Engineering
Systems Engineering ProgramCornell University
463 Upson Hall
phone: 607-255-3249
cell: 617-909-0644
web: https://sites.coecis.cornell.edu/bhplab/