Final Report
LUNAR SAMPLE CORING DEVICE

HEC 09
TEAM STEMbiosis

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We certify that the narrative, diagrams, figures, tables, calculations and analysis in this handout are our own work.

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1. Acknowledgments

This project has progressed with the guidance of our advisor, Samuel Ogletree. STEMbiosis thanks all of those at TSGC and Micro-G NExT, as they are the sponsor for this project. Additionally, thanks go to all the faculty of the UT Tyler mechanical engineering department, who have been very generous with their time throughout the scope of this project, including the faculty that assisted during the design review. A special thank you goes to Kristine Davis (NASA engineer), who has served as our NASA mentor.

2. Executive Summary

The goal of this project is to design, manufacture, and test a device capable of retrieving a core sample from the lunar surface. This project is a senior design project for UT Tyler with funding from the Texas Space Grant Consortium. The project mission statement was supplied by Micro-G NExT, which facilitates university students to address aspects of challenges faced by NASA. Explicitly this is TSGC-TDC-40 Micro-G NExT challenge five, lunar surface coring operations. The device will be tested within a neutral buoyancy lab (underwater testing) and must perform in those conditions. This coring device is an attachment to a handheld drill and is intended for single-handed operation. The design is meant for single-use service according to the design challenge requirements. This project, if selected, would see operation at the lunar South Pole as a part of Artemis missions.

The project was initially awarded to the group by a proposal submitted to TSGC. At which point, preliminary designs were then developed and submitted to Micro-G NExT. The team was selected to compete in the design challenge. At the beginning of the year, we were assigned to a NASA mentor.

The device is comprised of three main components: a core housing that will retain the core sample; a stabilization jig that will prevent the device from walking; a drill head that interfaces with the surface and allows for drilling. To date, the project has gone through both internal and external design reviews, manufacturing, and limited testing. Some of the critical design revisions that have taken place this semester have been to modify the helical flute structure of the drill head, and the length of the stabilization jig.

Due to manufacturing delays and current world events that have impacted the ability to coordinate in-person testing, the rigorous testing specifications that were initially established have yet to be completed. However, the testing that has been completed has proven to be extremely favorable. Currently, the project closeout is planned for August of this calendar year. Testing at the Neutral Buoyancy Lab will be conducted in September.

2.1 Concept Statement

While on the lunar surface, a core sample will be extracted from the ground by an astronaut. The core sampling device must be compatible with the Nemo Power Tools drill, an underwater divers drill. The device must stabilize the drill bit, then drill, core, and capture the sample. There is a heavy emphasis on the ease and fidelity of the coring operation.

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4. Introduction

The mission of this design challenge is to successfully create a core sampling device for lunar surface operation on the moon from concept and manufacturing to testing. The FA-1 design intends to address three main aspects, which are to drill to depth, sample containment, and drilling stabilization. The coring device enables astronauts to collect core samples and capture the core. The design requirements specified by Micro-G NeXT have been addressed and outlined with specific acceptance criteria that must be implemented. The design features are evaluated to verify that all design requirements have been satisfied. See Appendix A for more information on design specifications.

In addition to the design of the device, testing procedures were also arranged internally for design validation before submission of the project to NASA for external testing at the Johnson Space Center neutral buoyancy lab. The testing procedures that will take place internally, aim to experimentally verify that the core sample can be obtained safely in a variety of testing conditions. The external testing that will be completed at the neutral buoyancy lab will take a user through the core aspects of a successful coring operation.

4.1 Astronaut Limitations

During the project, our NASA mentor made us aware of the limitations that are within the confines of their suit. Finger dexterity is reduced by a great deal, as well as grip strength and limitations on the force applied by the astronaut. All of these concerns are implemented for the ease-of-use of this device. It is important to note that the initial testing suggests the durability of the device will allow for multiple uses. Multiple uses versus single-use operation are

distinguished because the device does not completely seal a retrieved sample. This device intends to retain the core sample to allow for extraction in a safe environment.

This device is intended to be stored within a cylinder in the stowed configuration. Before use, the astronaut will assemble the device and attach it to the chuck of the power drill. Once it is secured onto the drill chuck, the device can be placed on the surface and be used for core extraction.

The FA-1 design consists of a coring bit, a sample housing, a stabilizing jig, and off the shelf arbor mating mechanism to attach onto a standard drill. The design is created to utilize as many commercially available parts as possible also. It is simple to use and ensures safe operation for the user.

The project has shown many stages of progression. The engineering, development of ideas, and project improvement are core fundamental principles. Although the design has undergone many iterations throughout its lifecycle, the key elements remain constant.

5. Constraints

The lunar sample coring device must meet design constraints set forth by NASA, see these specifications in Table . The design constraints directly impact the configuration of the coring tool. Team STEMbiosis was challenged with developing a functional design that will operate within the required size, weight, and material constraints.

The tool must fit in its stowed position inside a 6” I.D. x 6” long cylinder. The design must be developed to fit this envelope without exceeding a maximum dry weight of 3 lbs. When developing a design to meet the size and weight constraints, selecting the appropriate materials is essential. The material must be light enough to maintain an acceptable weight but allow the mechanical properties to withstand the subjected loads and cycles during operation. The device will be tested in a saltwater environment, which means the materials must also be corrosion resistant. Size, weight, and material selection were the primary design constraints that were faced when envisioning an ideal design for the lunar sample coring device.

Table 1. Lunar Coring Device Design Specifications

Specification	**Description**	**Instrument to Measure**	**Acceptance Criteria**
Geometry constraint	Device shall not extend beyond the plane of drill chuck toward the user	Visually inspect	All components are below the chuck level of the drill
Interface	Device shall interface with 13mm drill chuck	Device Assembly	Device head adapts to 13mm drill chuck of the provided drill
External power	Device shall not be externally powered	Power/ pressure	No external power or pressure required
Packaging Size	Fit within 6" diameter X 6" long cylinder	Dimension	All components fit inside a mock storage cylinder
Weight	A dry weight of less than 3 lbs.	Weight	Device and connector have dry weight less than 3 lbs.
Cost	Institutional budget	Dollars	(Currently $2205.77)
Material specified	Stainless Steel, Aluminum and Teflon	Approval	Approved

6. Relevant Standards

Due to the extremely specific and narrow applicability of the design there are no relevant standards for this device. NASA typically does not reference standards within their own internal design documents for this reason. Other drilling standards were investigated and were found lacking due to the size of the device components. Nowhere on earth does it seem to be useful to extract a core sample of the dimensions described in the Micro-G NExT challenged document.

7. Design Details

The FA-1 coring device consists of three main components, which include the drill head, the core housing, and the stabilizing jig. The three main components were designed while the interfacing components were intended to be commercially available items that can be purchased from vendors. The intended function of the device is for the stabilizing jig to hold the device stationary, while the drill head, which is mated to the core housing, cores into the lunar surface utilizing a powered drill, capturing and containing the sample inside the core housing utilizing friction.

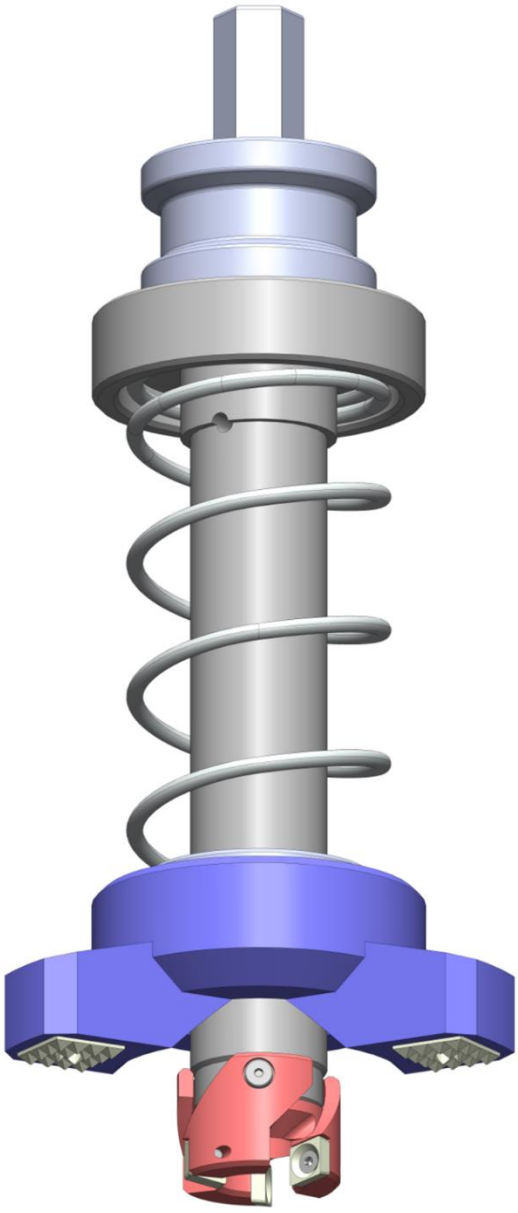


Figure 1. Isometric View of the Assembled Lunar Coring Device.

7.1 Drill Head

The drill head, displayed in Figure 1 and *Figure 2*, is a vital component of the FA-1 coring device. It contains the three carbide blade inserts which are mounted on the bottom to create a smooth cut through the surface, from which the target sample will be cored and extracted. This design decision was made, so if the carbide bits are damaged, they can be easily replaced. The drill head is mounted onto the core housing using bolts. Additionally, the drill head was manufactured from 17-4 PH stainless steel.

With the continuous evolution of the project, the drill head has proved to be one of the essential components of the overall device design. It is a result of multiple design iterations. During the initial research on how both concrete and ice cores are drilled, it was decided that a flat face bit would be best suited for this application. When the project first began, a total of four bits were chosen to be incorporated into the drill head. A decision was made to change the number of bits to three, since studies showed that more than three bits would not benefit operational efficiency. Also, more bits would ultimately increase the cost to manufacturing, due to the complex geometry. While the first concepts used a flat face due to shapes used for concrete core sampling, more research related to ice coring showed that helical flutes would be needed to extract cuttings away from drill head to ensure continuous operation. Helical flutes with a 45° angle were added to eject shavings from the drill head in hopes of mitigating ice build-up at the cutters.

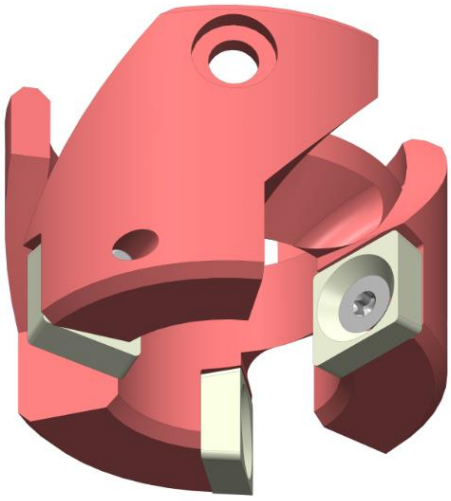


Figure 2. Drill Head

7.2 Stabilizing Jig

The second principal component of the FA-1 coring device is the stabilizing jig, shown in Figure 3. Its purpose is to hold the coring device in place with friction between the serrated gripper pads and the surface, while the coring device is in operation. The jig will be manufactured using Aluminum 6061, which meets the requirement for the device to be compatible with saltwater and chlorine environments.

The stabilizing jig was the component that may have seen the most significant geometry change as compared to earlier designs. A typical camera tripod inspired the original idea for the stabilizing jig. This idea started as three spikes that would contact the ground, but then evolved into three legs that had replaceable grippers for increased grip on surfaces. The idea for three legs considered to work best, since it would allow stabilization on flat surfaces, as well as uneven surfaces.

The stabilizing jig design with three legs and serrated gripper pads were ultimately decided on and deemed as potentially functional during the design review stage; it would require manufacturing and testing to verify. With a size constraint of having to fit within a six-inch diameter container, the jig was initially designed to have an overall leg diameter of 5.5 inches. The large diameter was initially designed because the larger base would theoretically be more stable and provide more room for growth if attachments were to be added. The teams NASA mentor, Kristine Davis, advised that a smaller diameter jig would be easier to handle. It would reduce weight and reduce the overall size, which leads to smaller packaging. A decision to decrease overall leg diameter was then implemented, which resulted in a reduction of its diameter by over two inches, making the new overall diameter 3-3/8 inches.

While changes were made to reduce the diameter, other notable changes were made that would lead to continuous design improvements. The proposed design of the stabilizing jig had chamfers on the bottom that would direct debris upwards at a 45° angle. A design change implemented to have the chamfers point downward at the same angle, to mitigate as much debris buildup as possible. The overall height of the jig was made shortened by nearly a ¼ inch by making the top of stabilizing jig flat instead of having the initial step where the bushing would be housed. This design change took place because the internal stop was moved onto the core housing instead of the stabilizing jig to simplify the design geometry.

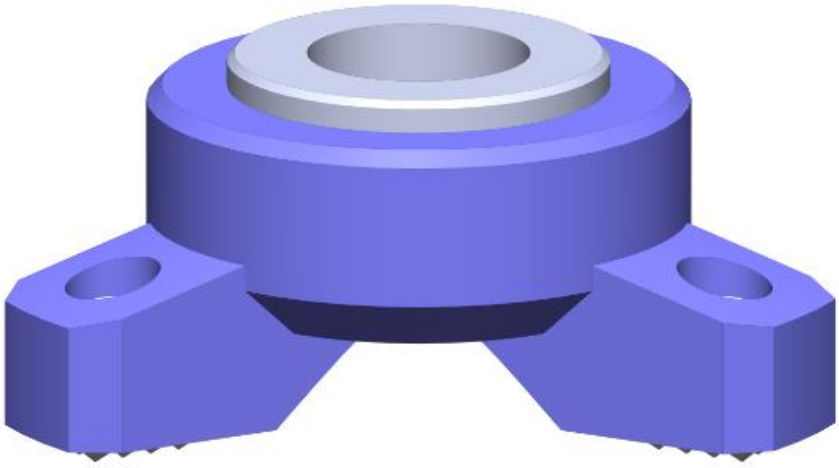


Figure 3. Stabilizing Jig

7.3 Core Housing

The core housing is the third component of the FA-1 Coring Device, which serves the purpose of a mating body for components, and it also plays a significant role of being the device's capturing and containment mechanism. The original idea was to create a sideload to shear the sample at the bottom of the core housing, then have the sample captured and contained in place due to surface friction during the sample extraction. The head of the core housing will be attached to a universal hole saw arbor drive, which will interface with the Nemo underwater drill used for testing at the NASA Neutral Buoyancy Lab (NBL). Since the arbor is commercially available, it can be adapted to any standard drill that accommodates a 25mm interface. The arbor creates the interface between the coring device and the drill; it is a crucial component of the design. The housing was also manufactured from 17-4 PH stainless steel.

The core housing throughout the months progressed with small changes compared to the drill head and stabilizing jig. As mentioned previously, the method of providing an internal stop

to indicate target coring depth moved the placement of the stop from the stabilizing jig to the core housing. This was achieved by incorporating a series of steps that were machined into the core housing, so once it contacted the stabilizing jig, it would bottom-out and prevent continued travel. These details are shown in Figure 4.

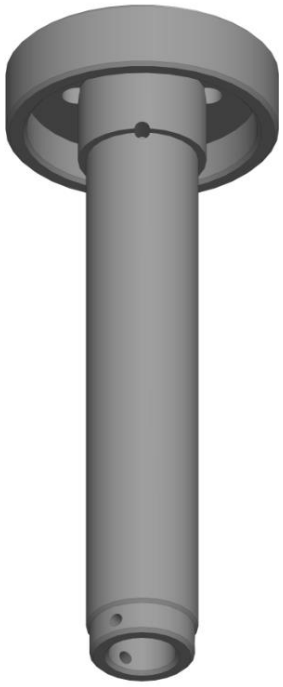


Figure 4. Core Housing

7.4 Selection Choices

Material choice was another aspect of the project that was refined, due in part with outside sources. The materials used on the core housing were not changed to 17-4 PH until the vendor who machined the component suggested the material change for cost savings. The team initially chose to use 316 stainless steel for both the core housing and drill head components due to acceptance criteria from NASA, which required material that will not cross-contaminate with the specimen. This stainless steel was also chosen because of its high strength properties, the reasonable cost compared to titanium, ease of machinability, and availability.

After sending in the drawings for quotes to the machine shop chosen for the project, an agreement was reached, and manufacturing commenced. The machine shop would eventually notify the team that they did not have enough 316 stainless steel on hand and would need to order more to finish both pieces. The lack of material would extend lead-time by one extra week. The machine shop communicated that they had an abundance of 17-4 PH stainless steel on hand that they could offer at the same price as 316 stainless steel and the group could use that as a substitute if allowable. After reviewing the acceptance criteria, it was decided that 17-4 PH stainless steel would be acceptable and was a better material at no additional cost, therefore satisfying the team's budget.

With the calculations outlined in Appendix F, it was determined that with the materials chosen and design geometry, that material failure would not pose an issue. The calculations show a factor of safety of thousands of percent higher than can be reached by the forces applied by the astronaut in a real-world application. Having these calculations and knowing the stainless steel would prevent cross-contamination to specimens, it was decided 17-4 PH stainless steel and 6061 aluminum would be the best material for the design.

8. Black Box and Functional Diagrams

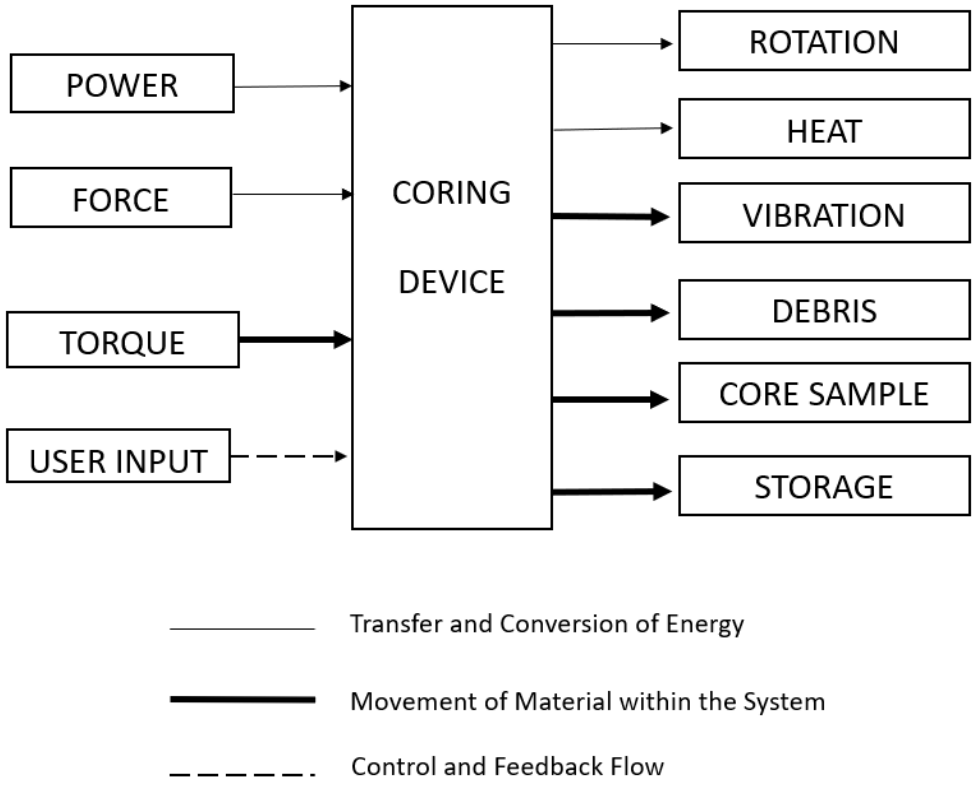


Figure 5. FA-1 Function Diagram

The black box diagram in Figure 5 depicts the completed assembly in operation. The coring device meets with a handheld power drill, which provides the power and torque. The user operating the power drill will apply a downward force and set the speed of the drill. As the coring device breaks the surface and proceeds to drill down heat, vibration, debris are all created. The torque is converted into rotational energy within the drill itself. This rotational energy, alongside the downward force, removes the necessary material. As drilling continues, a core sample is retained within the core housing. After sideloading the drill and the coring device, the core sample is stored within the housing. The user then proceeds to lift the drill and coring device to retrieve the core sample.

9. Risks Involved / Hazard Assessment

The most critical component within the engineering design process is the process of identification, analysis, and assessment of risk. The purpose of risk assessment is to guide engineers to identify and analyze hazards and assess the risk to maximize the safety of end-users during assembly, operation, and storage of the device. Operational standards, guidelines, and proper product handling methods can be applied to minimize the presence of potential hazards.

During the early stage of design, risk assessment methods were used to create procedures that intend to avoid, mitigate, and manage hazards during operation. Furthermore, these procedures are classified into the following four steps:

1. Observation: visual inspection of the device and each component to identify pinch points, sharp edges, and joints.
    - Always wear proper personal protective equipment (PPE)
    - Follow instructions for preparation of test samples thoroughly
2. Assembly: connection of each component and carefully secure screws.
    - Be mindful of sharp edges on carbide bits
    - Verify a secure connection between the arbor and core housing
    - Secure the connection of arbor to the drill chuck
3. Operation: Operation of the device following the guidelines.
    - Do not place hands directly below drill head
    - Be mindful of rotating parts
    - Operate device with one hand.
    - Avoid using secondhand contact with rotating parts of the device.
4. Storage: a collection of the core sample and storage.

- Once drilling is complete, stop the operation and move the device to the proper location for sample extraction from the core housing.
- Disconnect the arbor from the drill chuck mate
- Disconnect the arbor from the core housing by rotating the arbor counterclockwise.
- Insert dowel from coring bit side and push-up ward the sample core to the core housing head.
- Carefully inspect the coring tool and drill for damaged parts.

9.1 Failure Mode Analysis

Process: Lunar Core Sampling

Table 2 Failure Mode Analysis

Failure Mode	**A) Severity** Rate 1-10 = Most Severe	**B) Probability of Occurrence** Rate 1-10 = Highest Probability	**C) Probability of Detection** Rate 1-10 = Lowest Probability	**Risk Priority Number (RPN)** A*B*C
1) FA-1 Coring Device stuck beneath surface	10	5	3	**150**
2) FA-1 Coring Device Unable to reach depth due to ice build up	7	8	3	**168**
3)Core Housing breaks	10	2	3	**60**

4)Stabilizing Jig breaks	7	1	1	**7**
5)Drill Head breaks	10	6	2	**120**
6)Thrust Needle Bearing gets stuck	4	7	1	**28**
7) Drill loses power	10	4	1	**40**
8)Sample irretrievable surface	10	5	3	**150**
9)Drill head screws shearing	9	6	3	**162**

10. Results

Initial testing was favorable with Type-N mortar mix, with the average applied load being 17.6 lbs. at 720 RPM during operation, as shown in Figure 6. This was validation that the design and geometry of cutting bits would in fact, core through the test mediums. The test fixture used is shown in Figure 7, which depicts the core housing and drill head connected to a drill press to test, and ultimately was able to accomplish the task and provide the core sample as shown in Figure 8. The core sample retrieved is considered a Grade C sample based on Figure 7 below.

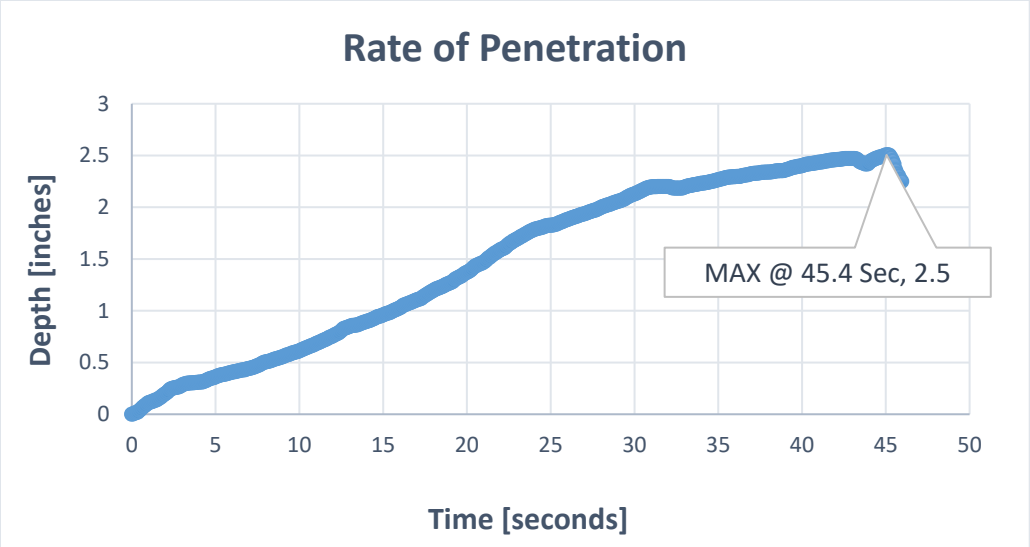


Figure 6. Rate of Penetration of depth over time.



Figure 7. FA-1 device during operation.



Figure 8. Core sample retrieved from the experiment

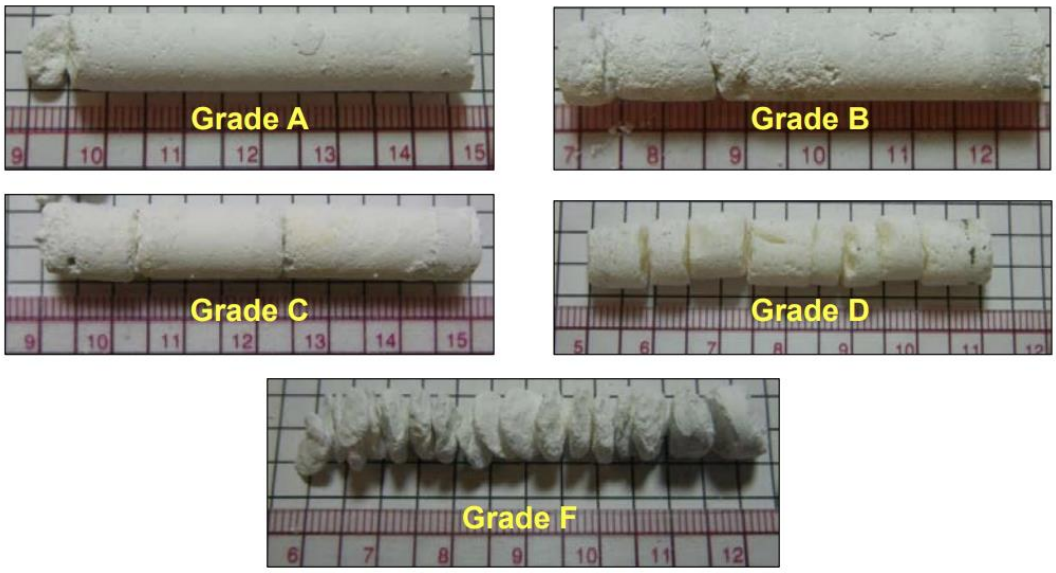


Figure 9. Core sample grading reference

11. Final Simulation and Results Comparison

Due to the complexity of simulating the device no simulations were done prior to testing. The only calculations that were performed prior to manufacturing the device was to obtain factors of safety.

12. Bill of Materials

Table 3 Bill of Materials

Item #	Part Name:	Mfr. Part number:	Quantity:	Price per Item:	Total Price:
1	Core Housing	COH1	1	566.66	566.66
2	Stabilizing Jig	STJ1	1	816.69	816.69
3	Drill Head	DRH1	1	566.65	566.65
4	serrated grippers 8 1/2" x 1/2"	84905A52 (McMaster-Carr)	5	10.71	53.55
5	#10-32 x 3/8" LG Button Head Cap Screw	98164A177 (McMaster-Carr)	1	8.74	8.74
6	#6-32 x 1/4' Low Head Socket Head Cap Screw	93615A110 (McMaster-Carr)	1	13.00	13.00
7	Ts-25 (45x6M2) Torx Screw	3288A96 (McMaster-Carr)	8	2.95	23.60
8	7/8" Shaft Dia. 1-1/8" Housing 3/4" Lg. Flanged Sleeve Bearing	7815K52 (McMaster-Carr)	2	6.06	12.12
9	Thrust Needle-Roller Bearing for 1" shaft diameter, 1-9/16" OD	5909K36 (McMaster-Carr)	3	3.40	10.20
10	0.032" Thick Washer for 1" Shaft Diameter Needle-Roller Thrust Bearing	5909K49 (McMaster-Carr)	6	1.23	7.38
11	Carbide Insert (Cutter)	3244A775 (McMaster-Carr)	8	12.62	100.96
12	Torx L-Key with Standard Tip, T8 Size, 1-3/4" Overall Length	6959A14 (McMaster-Carr)	2	2.97	5.94
13	Needle-Roller Thrust Bearing for 1-1/8" Shaft Diameter, 1-3/4" OD	5909K37 (McMaster-Carr)	3	3.40	10.20
14	0.032" Thick Washer for 1-1/8" Shaft Diameter Needle-Roller Thrust Bearing	5909K51 (McMaster-Carr)	6	1.68	10.08
				Total Price:	$ 2,205.77

The team utilized the full allowed budget of $2,205.77 from University of Texas at Tyler.

13. Economic Feasibility

A comparison between prototyping and single manufacturing runs versus mass production is not applicable within the scope of this project. The final application of this device if it to see operation on the lunar South Pole would entail manufacturing one or two more devices in total. For this reason mass production efforts and inquires were not explored.

14. Discussion

As a result of world events, the available testing was completed using the drill head and core housing, as shown in Figure 7. The integration of all other components that complete the FA-1 assembly will happen alongside the startup of normal business operations.

An initial concern of the project was the method for sample capturing and containment by using only surface friction. The team's prior research and testing showed that it would be sufficient for accomplishing both tasks. As a result of testing, the initial design validated that friction alone would perform both tasks sufficiently.

Initial testing, as well as previous research, also shows that the design of the helical flutes plays an essential role in how cuttings were directed away from the drill head. During the ice core testing, penetration into the ice happened without complications, and the carbide bits performed as planned. At half an inch depth was where an issue was faced, and the coring device would not move any further downwards from that position without exceeding projected forces applied to it. The core housing did capture and contain an ice sample of half an inch in length. However, a buildup of ice on the flutes was observed. This is believed to be the reason why the device stopped at 0.5-inch depth and would not continue further.



Figure 10. Ice buildup on Drill Head Flutes

For the initial concrete coring sample test, the issue with sample buildup in the flutes seen with ice was not present. While coring concrete, a depth of 2.5 inches was reached. The device was then retracted due to being unable to continue further, without additional forces being applied. It was then observed that despite being torqued with Loctite in place, the bolts attaching the drill head to the core housing, backed out due to external contact. The bolt heads were deformed by contact when rotating within the concrete bore. As part of the initial design, a countersink hole for the bolt was chosen to attach the drill head to the core housing, so that once both parts were mated together, the bolts would be flush to the surface of the drill head. It was unexpected for bolts to make contact with the drill bore during operation. The machined design incorporated a loose fit where the drill head mates to the core housing. Upon assembly, the drill head was not entirely centered on the core housing. Consequently, the bolts were slightly protruding beyond the outer diameter of the drill head.

14. Recommendations

Several changes could be made to the current design iteration to improve the coring tool. The changes would address three concerns: debris mitigation, ice drilling compatibility, drill head durability. The structure of the helical flutes could be altered to make the device more capable of drilling into ice. A plexiglass shroud add-on for the stabilizing jig could be added for dust/ice shaving mitigation. During testing, ice shavings and dust did become apparent, and a shield could help contain them better for a potentially less hazardous environment. After discussions with the NASA mentor, mitigating risks for lunar dust containment helps reduce unwanted debris on the spacesuits.

Currently, the initial data indicates that the clearance between the core housing and the drill head needs to be reduced. The original idea was to save money by allowing for greater tolerance. The tolerance stacking thus enabled a gap where vibrational effects could interfere with the screws; this also reduced thread engagement length. Due to vibrational effects, the screws tend to be pushed away from the core housing. This necessitates that the screws be replaced between each operation, or that a small modification of the core housing would be warranted. With the core housing modification, the screws would have reduced vibrational effects as well as increased thread engagement, resulting in a more stable design.

Again, addressing the screws at the base of the device. The screws also protrude outward from the drill head, resulting in frictional effects. This drag results in unnecessary wear on the screws and threads. By modifying the drill head by increasing the depth of the counterbore, the screw heads would be appropriately recessed. The low-head socket head cap screws were chosen for their low profile. However, this is still not sufficient. The current drill head can be modified to achieve this by increasing the depth of the counterbore. This change will also increase thread engagement.

A new core housing may also be considered to ensure the appropriate fit with the drill head. This would allow for the snug fit previously mentioned and would cost between $600 and $900. With an increased counterbore depth being of nominal costs. The project team has funding to complete the above modifications and commission the work over the summer.

If the intention is to make the device capable of drilling into ice, then the helical flute structure should be extended to the end of the drill head. This would add more complexity to the design geometry and would cost a minimum of $2500 for the drill head. It has been advised that to drill to a substantial depth in ice, flutes should also be added to the core housing itself.

However, this would increase the cost of the core housing. The decision to implement flutes on the core housing could not be made as easily, due to the ramifications it would have on the sliding fit where the core housing interfaces with stabilizing jig.

Delivery of all parts and documentation will take place before August 31st as per the Micro-G NExT competition guidelines. Currently, all members of the project team, as well as NASA Engineer Kristine Davis has agreed to compete in September. The University of Tyler has designated Samuel Ogletree as the faculty advisor, who will also continue to work with the team until the Micro-G Next event.

It should be noted that during the project, additional clarifications were made in April that the final testing shall be completed with sandstone. Initially, testing specifications considered evaluation of the design and all possible testing conditions. The testing guidance was initially vague and thus required an extensive testing framework.

14.1 Deviations

Due to recent world events, certain local ramifications have had an impact on the schedule and completion of the project. As of the date of this report, the manufacturer still retains possession of the stabilization jig. The manufacturer was approved to manufacture the FA-1 coring device on February 14, 2020; a lead time of two weeks maximum was quoted. After six weeks, the core housing and drill head were received by the project team. It was also in February that team lead decided to alter testing. The preferred ice testing requires a significant amount of freezer space. The decision was made to forgo the creation of ice specimens of the size required. If given the opportunity, the team would like to test on ice to see whether different RPM and force combinations would yield different results than previously discussed. It is inconclusive as to whether the design can operate as expected in those conditions.

Aspects of the design that have yet to be tested include the interfacing of the core housing and stabilization jig. The tolerance is specified to conform to a running fit of classification; this is another aspect of the stabilization jig itself. Without the completed assembly, the spring and gripper pads have yet to be tested. Currently, there is no cause for concern in any of these parts in terms of their durability. However, it is unknown how effective the gripper pads will be in preventing walking during drilling operations.

14.2 Design limitations

One aspect that the design lacks is a covering around the spring and the rotational components, which would add further protection for the user. A covering is not mission-critical and was requested as something to be explored by the NASA mentor. There are no available designs that will satisfy this request that can be recommended at this time.

Additionally, within the design review, the question of breaking and retaining a core sample was questioned. The device operates by retaining the core sample with friction and breaking the sample at the bottom via side loading. Initial testing proves that sideloading is a viable option. There is no ready-made solution to these problems on this scale. In similar applications with larger diameter coring tools, there are many solutions. Scaling down such technology (coring dogs, soil retainers, or similar) seems infeasible with the specifications of this project.

15. Conclusion

There are a series of small modifications that are currently under review by the project team. After these modifications are weighed and acted upon, rapid prototyping will occur accordingly. This prototyping shall not be with 3D printed plastic but rather with the end-use materials. It is important to note that the project team is constrained on a number of prototypes by financial limitations. There was a question as to whether an outside manufacturer shall prototype only one design. The project team has contacted several machining service providers to establish a relationship. These service providers have agreed to supply the team with a quote for manufacturing costs incurred while utilizing their services. However, if the project team has access to CNC equipment, then such outside manufacturers shall not be needed, and a resultant cost-saving shall be accrued. The modular design of the FA-1 coring tool will allow for multiple permutations to be tested quickly and effectively for little added costs compared to the manufacturing of one prototype.

Further next steps include reaching out to the local community in order to provide outreach services. These outreach services can be found within the appendix and seek to motivate the youth to pursue STEM education. This is encouraged by both the project sponsor and the end client.

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Appendix A – Poster

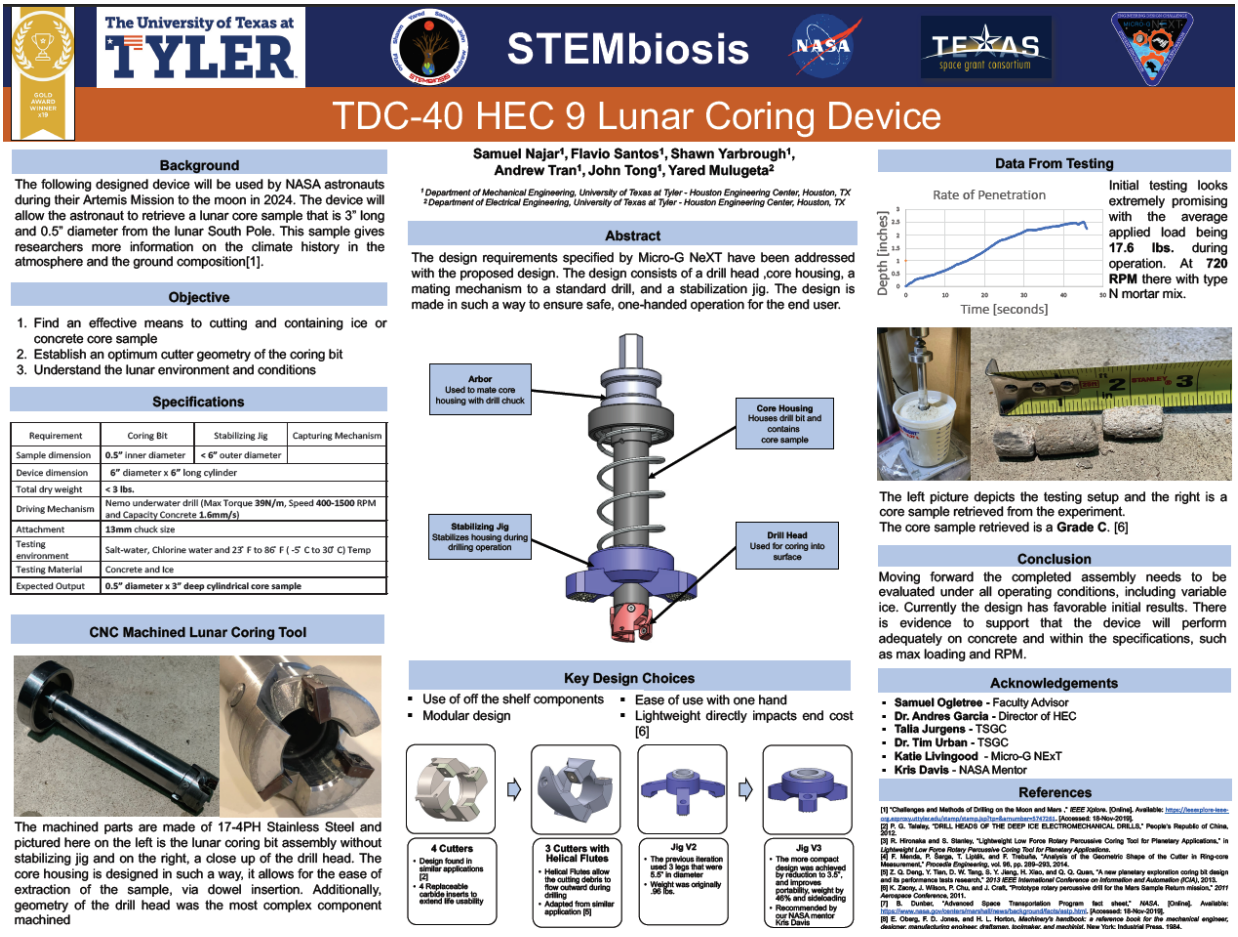


Figure A. 1 TSGC showcase poster

Appendix B – Acceptance Criteria

Table B.1 Acceptance Criteria

Specification	**Description**	**Instrument to Measure**	**Acceptance Criteria**
Size of the core sample	Device shall collect core sample 0.5" diameter x 3" depth	Length	sample must measure a minimum of 0.5" diameter x 3" long
The shape of the core sample	Device shall collect a cylindrical core sample	Shape	must be cylindrically shaped
Test material medium	Device shall core through concrete or ice	Durability	Must be able to core through concrete and ice without failure
Geometry constraint	Device shall not extend beyond the plane of drill chuck toward the user	Visually inspect	All components must be below drill chuck
Interface	Device shall interface with 13mm drill chuck	Interface	Must be able to adapt to 13mm drill chuck of drill provided
External power	Device shall not be externally powered	Power	Device must not be externally powered or pressurized

Table B.1 Continued

Specification	**Description**	**Instrument to Measure**	**Acceptance Criteria**
Capturing and containment	Device shall capture and contain the core when drill is removed from target	Capturing and Containment	Must keep core sample held in place when removed from target
Packaging size	Device shall fit within 6" diameter x 6" long cylinder	Dimension	All components must fit inside mock storage cylinder
Working Environment	Device shall operate underwater Device shall be compatible with chlorine or salt-water	Visually inspect	Must remain operational after use
Weight	The device shall have a dry weight of less than 3 lbs.	Weight	Must have dry weight less than 3 lbs.
Testing Temperature	Device shall operate within 23°F to 86°F	Temperature probe	Must still be operational in require temperature range

Appendix C – Testing Procedures

Phase one of testing will measure force and RPM as the device drills to the desired depth. The test acceptance criteria will consist of drilling to depth three times within ten attempts. The RPM will be measured with a hall effect sensor; force applied will be measured with a load cell. The expected outcome is to achieve drill depth within time and force constraints.

Phase two will consist of three parts: (a) dry performance in various test media, (b) submerged operation, and (c) surface variation. Phase two will be used to judge the quality of the core sample and to test the design rigorously. The objective is to evaluate the full extent of the design capabilities. Five different test media, three surface variants, and evaluation of the core sample itself. The previous test metrics will be evaluated as well as core sample grading. The expected outcome is to have sample extraction from the tests performed while maintaining a working device.

Phase three will be an ease of use study. This test will be used to prepare for the final testing in the Neutral Buoyancy Lab (NBL). The test will consist of 10-20 people in groups of five to six persons per testing session. Each test session will begin with a safety briefing followed by an operational briefing (see operations plan below). There will be an exit survey used to evaluate user interaction. During test day at the NBL, the design team will have five minutes to walk the operator through the operations plan. The end-user will have already read themselves into the safety documents and operations plan. The test population will test the design without prior knowledge of how the device works and shall be instructed on the proper use of the day of testing. The expected outcome is to have feedback that will be used to guide the delivery of operation instructions to end-user.

Table C.1 Device Testing Media

Type	Description
Ice I	Ice with sediment dissolved on a 10% mass fraction basis.
Ice II	Purified with directional Freezing
Lime Rock Mix	Complies with ASTM C926
Concrete I	Exceeds the compressive strength requirements of ASTM C387
Concrete II	Meets ASTM specs C 1714 and C 270 for type N mortar

Preparation of Test Sample Mediums

All test mediums prepared shall have a minimum of 4 inches in thickness

- Ice 1 sample medium shall be prepared by the following method:

  (1) Chill soil that consists of a sand-clay mixture

  (2) Mix the sand-clay mixture with water in watertight container and place into a large freezer at 25°F

  (3) Agitate water continuously during the freezing process every 5 minutes until frozen

- Ice 2 sample medium shall be prepared by the following method:

  (1) Fill the container with purified water and place into a large freezer at 25°F

- Lime Rock sample medium (Lime-Mason Mix, 1800 PSI compressive strength mix) shall be prepared by the following method:

  (1) Pour half bag into a wheelbarrow (40 lbs).

(2) Add half amount of suggested clean water (2.5 quarts).

(3) Mix thoroughly until the consistency is uniform.

(4) Pour two quarts into the container. (Repeat twice for two samples)

(5) Let air dry for a minimum of 24 hours.

- Concrete 1 sample medium (High Strength Concrete, 4000 PSI compressive strength) shall be prepared by the following method:

(1) Pour half bag into a wheelbarrow (40 lbs).

(2) Add half amount of suggested clean water (1.5 quarts).

(3) Mix thoroughly until the consistency is uniform.

(4) Pour two quarts into the container. (Repeat twice for two samples)

(5) Let air dry for a minimum of 24 hours.

- Concrete 2 sample medium (Concrete Mortar Mix, 750 PSI compressive strength) shall be prepared by the following method:

(1) Pour half bag into a wheelbarrow (30 lbs).

(2) Add half amount of suggested clean water (2 quarts).

(3) Mix thoroughly until the consistency is uniform.

(4) Pour two quarts into the container. (Repeat twice for two samples)

(5) Let air dry for a minimum of 24 hours.

Table C.2 Load Requirements

Description	Max Load/Torque/Revolutions
Applied Axial Load	60 lb-f
Max Torque	28.7 lbf*ft
Max Revolutions	1500 RPM

Table C.3 Temperature Ratings

Description	Temperature (ºF)
Minimum	23
Maximum	86

Table C.4 Testing Acceptance Criteria Matrix

	Category	Measuring Method	Acceptance Criteria*
1	Coring Housing	Electronic Digital Caliper	Core a sample of .5" ± .05" diameter x 3" ± .3" long dimensions.
2	Stabilizer Jig	Electronic Digital Caliper	Prevent the bit from walking underwater. Linear distance travel shall be <1/8" (Concrete II)
3	Device Assembly	Visually inspect	The device must work both in water and dry.
4	Drill Time	Stopwatch	The device drill to depth within 5 minutes from the *"ready configuration*".
5	Force Allowance	Load Cell	The device shall not require more than the maximum allowable force to operate.

Table C.5 Continued

	Category	Measuring Method	Acceptance Criteria*
6	Linear Distance	Rotary Encoder Sensor	The device shall not travel more than 3.25 inches
7	RPM Allowance	Hall effect sensor	The device shall not require more than the maximum allowable RPM.
8	Temperature Range	Temperature probe	The device shall operate both min and max temperatures. (1 successful attempt)
9	Dry Capable	Open-air test	The device shall operate when the device is in the open air.
10	Wet Capable	1” water layer above the test media	The device shall be compatible with chlorine or salt-water.
11	Safety	Recordable injuries accounted for	The test was conducted without injury.
12	Exit Survey	A questionnaire with 5 points scale or true/false questions exclusively	A survey was collected.
13	Surface Variant	Grade at or exceeding 15°, the roughened surface shall have divots made randomly on the surface.	Test conducted on the graded and roughened surface variant.

**Each part shall perform as intended without effecting fit, form, or function.*

Table C.6 Testing Matrix

Test	Test Media	Number of Tests	Acceptance Criteria*
Phase 1 (validation)	Ice II Concrete II	Max of 10 attempts. The test will stop with three successful attempts in each medium.	4,5,6
Phase 2a (dry test)	All	3 per medium.	1-8
Phase 2b (underwater test)	Ice II Concrete II	3 per medium.	1-4, 9
Phase 2c (surface variant)	TBD	3 per variant.	1-8, 12
Phase 3 (optional ease of use study)	Concrete II	2 Operations per person.	10,11

**Each part shall perform as intended without effecting fit, form, or function.*

Experimental Design Internal Testing

Apparatus

The following apparatus is required for testing:

- The lunar core sampling device
- Custom drill press (with load cell, hall effect, and encoder sensors)
- PPE (gloves and safety glasses)
- Ice samples
- Lime Rock sample
- Concrete samples
- Tub for submerging samples while coring

Assembly of Lunar Core Sampling Device

Before assembly, all machined components shall be inspected for any burrs or rough edges. Parts shall also be inspected with digital calipers to ensure dimensions match engineering drawings.

With assembly components outlined on the bill of materials, the assembly shall be built to drawings using torque specs provided.

Assembly of Test Equipment

The test jig will be comprised of a drill press and the attachment of the following array of sensors below:

- Hall effect sensor – used to measure the magnitude of the magnetic field and installed onto drill press by 3-D printed apparatus. RPM detection will be done using a magnet

that will be attached to the drill, and the Hall effect sensor will be parallel to it. Every pass that occurs during a rotation, the magnetic field will be detected and will be utilized for rotations per minute (RPM) on the lunar coring device.

- Encoder sensor – measures incremental motion in a PWM signal as a defined number of cycles in a 360° revolution of the shaft and then converts into a measure of position. This is done by using a light emitted from the internal diode, which passes through a transparent patterned disk and converts the light into a light beam and picked up by a photosensor, which then produces a sinusoidal wave, and is transformed into a square wave for the counter. This will allow us to formulate a rate of penetration (ROP)
- Load sensor – using four strain gauges configured in a wheat stone bridge circuit formation. A constant voltage is supplied, and the change in the voltage out will be converted to data that will be collected as force (lb) applied during the downward motion of coring cement or ice sample.

With the test jig components outlined on the bill of materials, the assembly shall be built to engineering drawing. All electronic sensors must be attached and calibrated for accuracy. An Arduino MEGA 2560 will then be connected and set up for data acquisition.

Testing

Testing shall take place within a tub with water to simulate conditions that will take place in the NBL lab at Johnson Space Center. Similar to the wet conditions as well as dry conditions where testing shall occur when not submerged. Proper PPE shall be worn per the JSA set in place. Testing shall take place as follows:

1. The test specimen shall be inserted into place on a test jig.
2. Drill press shall be forced downward with a force of less than 60 lb-f applied.
3. Force shall be applied downwards until the internal stop on the core housing has contacted its stop point.
4. Once the final drill depth of 3.5” has been reached, drilling shall stop.
5. The drill shall then be retracted upwards and powered off.
6. Tests shall repeat three times for each medium in dry conditions where jig and samples are not submerged in water.
7. Tests shall then be repeated three more times for each medium in wet conditions with test jig and samples submerged into water covering sample with a minimum of 1”.

Appendix D – Mechanical Drawings

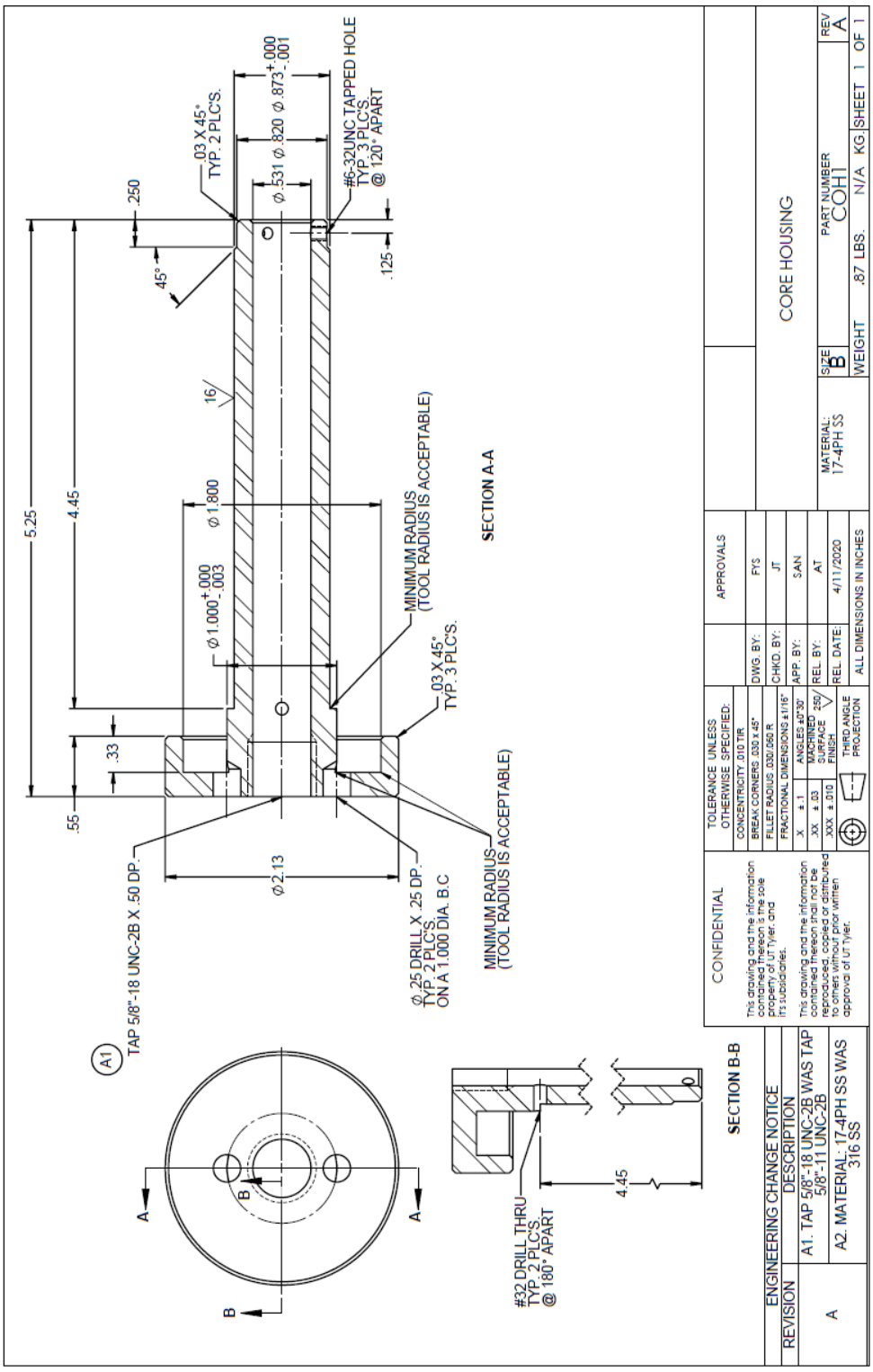


Figure D. 1 Auxiliary view of the Core Housing

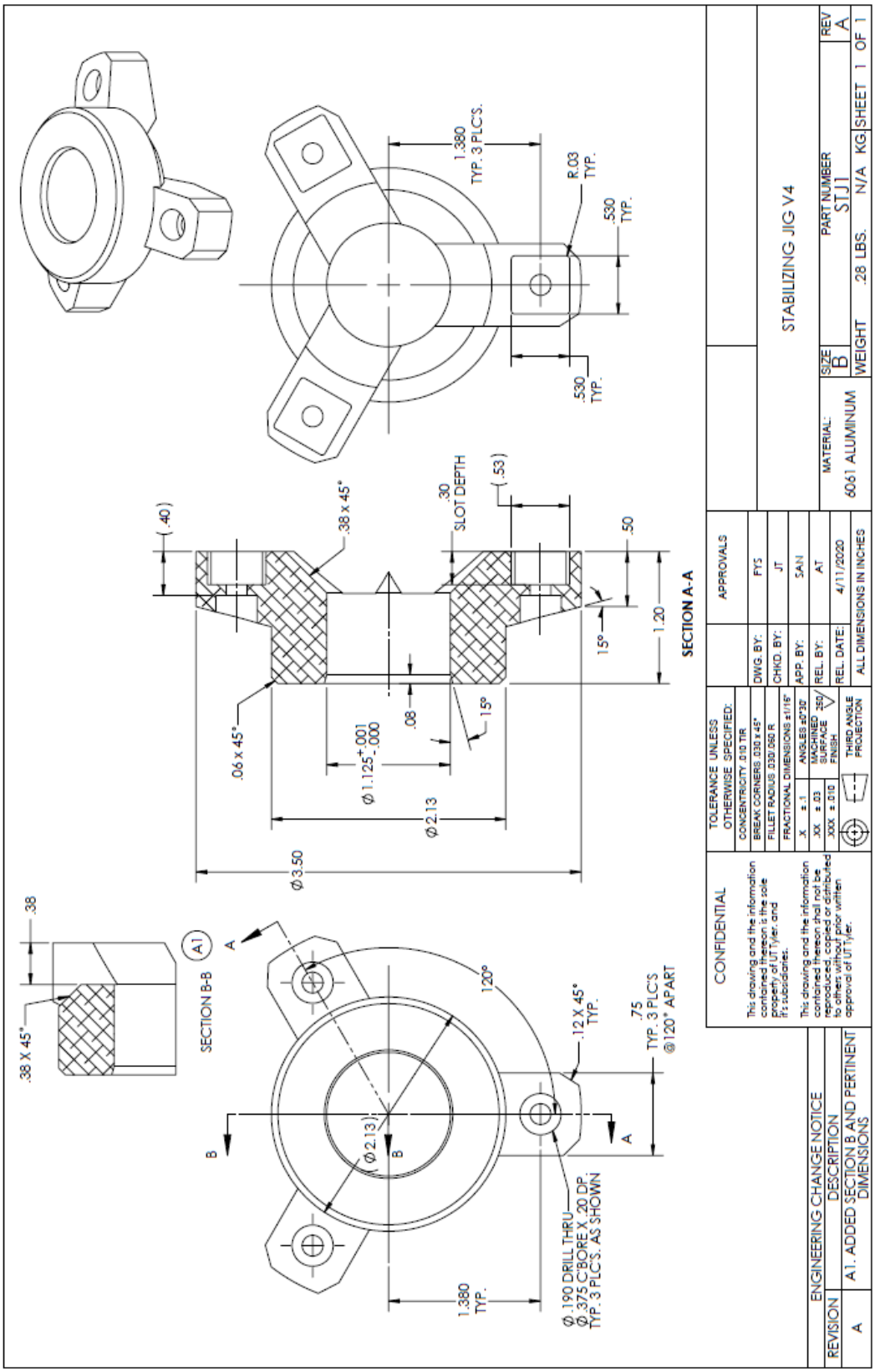


Figure D. 2 Auxiliary View of the Stabilizing Jig

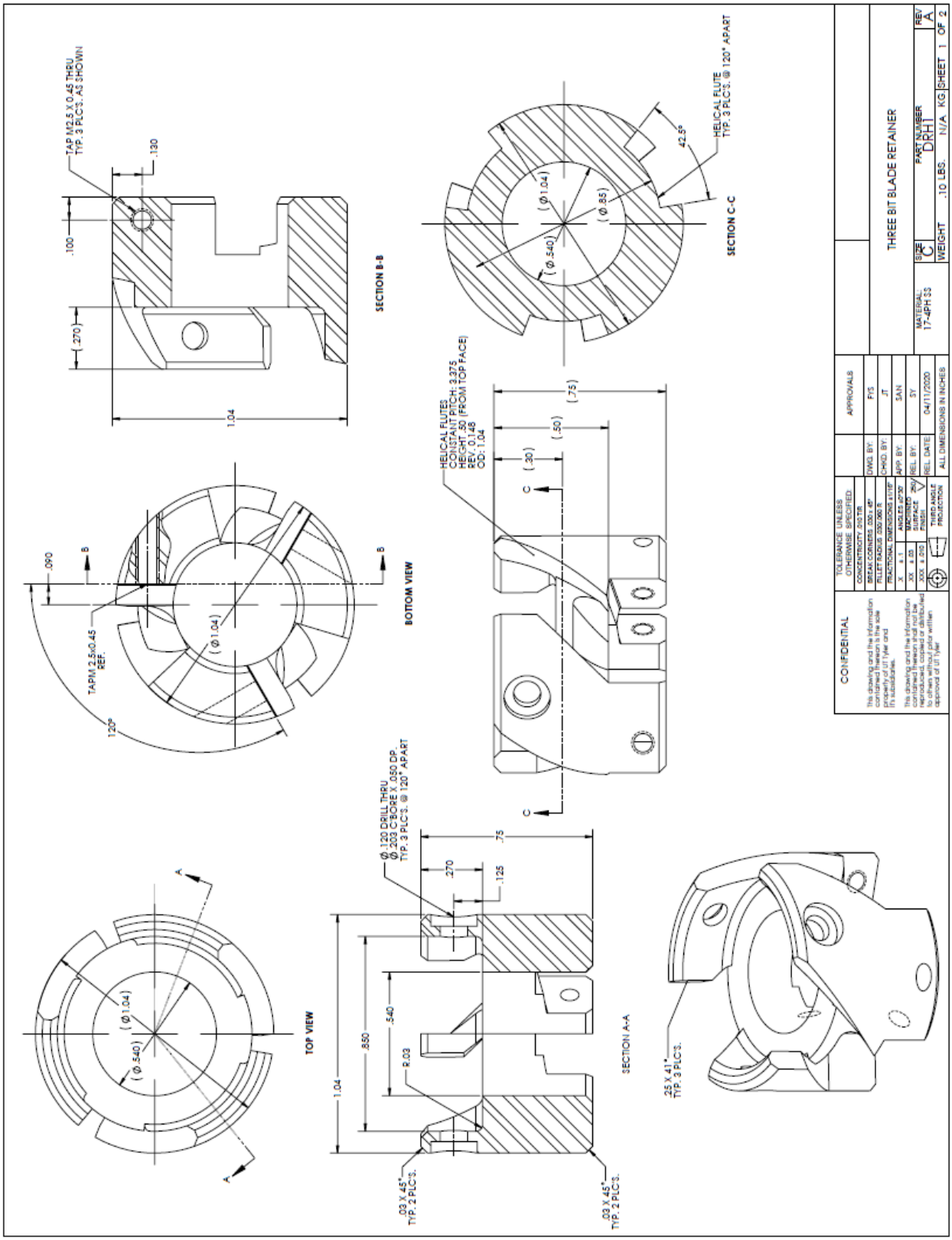


Figure D. 3 Auxiliary View of the Drill Head Sheet 1 of 2

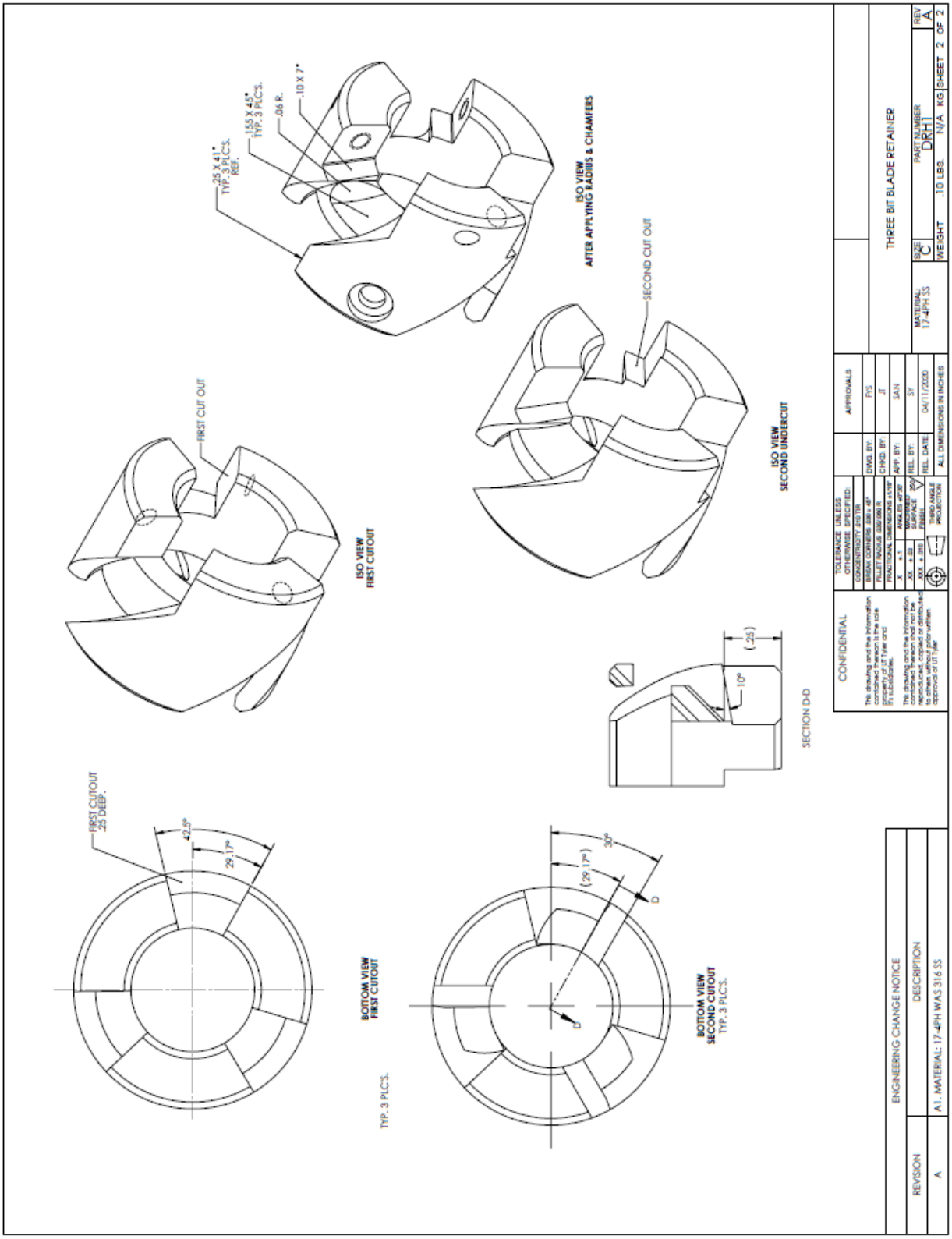


Figure D. 4 Auxiliary View of the Drill Head Sheet 1 of 2

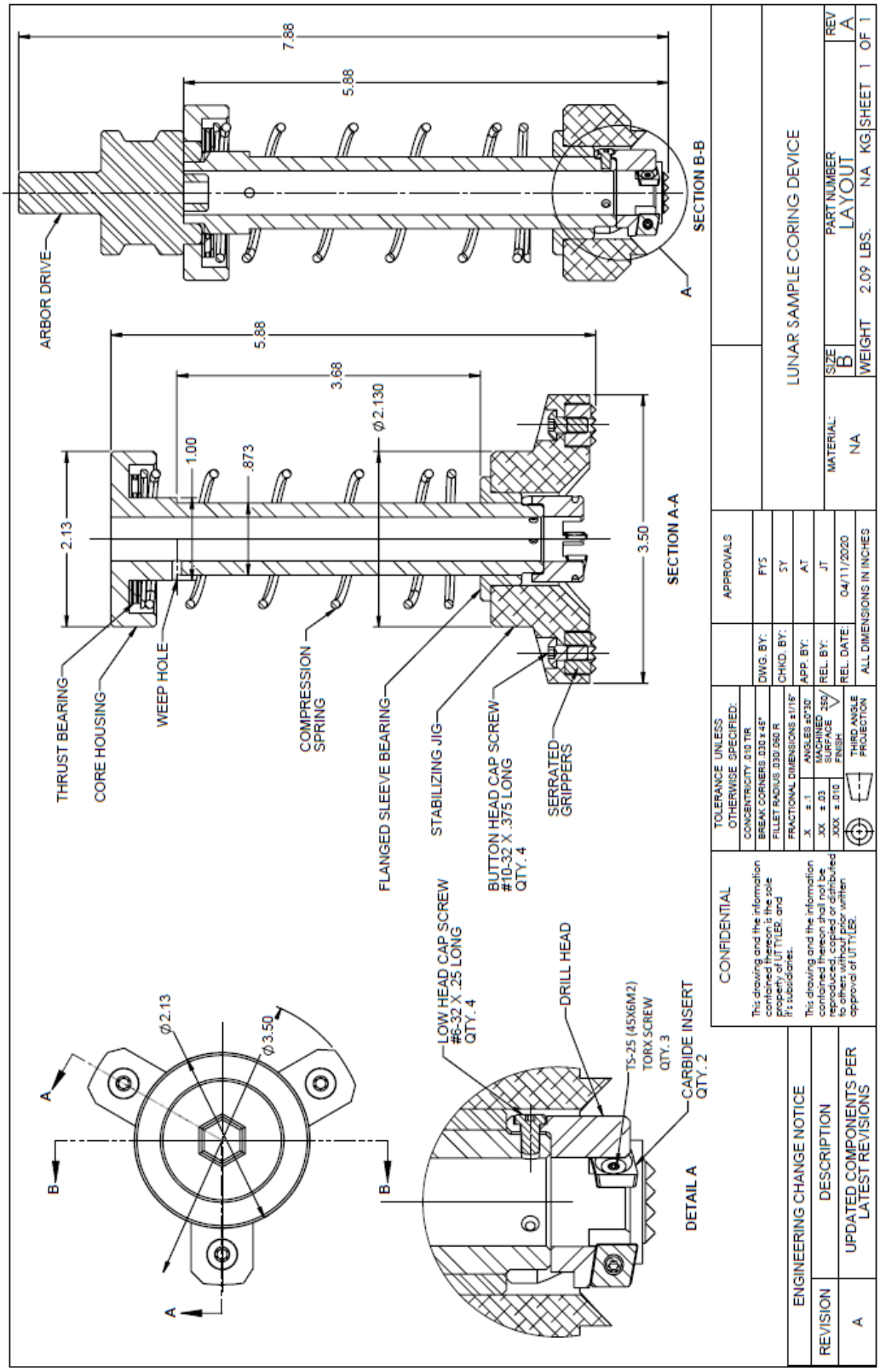


Figure D. 5 Detail view of the Lunar Coring Device with Jig

Appendix E – ARCI Chart

Table E. 1 ARCI Chart

WBS	Work Item	Andrew	John	Flavio	Shawn	Yared	Samuel
	Lunar Sample Coring Tool						
1	**Problem Definition**						
1.1	Gather Data	P	S				
1.2	Study Feasibility		S		P		
1.3	Prepare Report		P		S		
2	**Coring Tool Analysis**						
2.1	Ease of Use Study			S			P
2.2	Analyze Existing Systems	P			S		
2.3	Define User Requirements						
2.4	Prepare Report					P	S
3	**Coring Tool Design**						
3.1	Stabilizing Jig	S		P			
3.2	Drill Head			S	P		
3.3	Core Housing		S		P		
3.4	Prepare Report	S					P
4	**Coring Tool Development**						
4.1	3-D Model Prototype				P	S	
4.2	3-D Print		S		P		
4.3	3-D Model Assembly			S	P		
4.4	Functionality Verification	S			P		
4.5	Prepare Report			S	P		
5	**Testing**						
5.1	Drilling Concrete				P		
5.2	Drilling Ice		S				P
5.3	Drilling Limestone				S	P	
5.3	Prepare Report	P		S			
6	**Implementation**						
6.1	Training			S		P	
6.2	Lunar Conversion	S	P				
6.3	Prepare Report		P			S	

KEY: P = Primary Responsibility S = Support Responsibility

Appendix F – Design Calculations

Input: Cutter Movement

$WOB := 0.612\ kg \cdot 9.81\ \frac{m}{s^2} = 6.004\ N$ — Weight on Bit (N)

$D_b := .6 \cdot m$ — Diameter of Bit (m)

$a := 1$ — Rock Formation Constant

$b := 1$ — Rock Formation Constant

$n := 1500\ rpm$ — Drill Head Rotation Speed (rpm)

$ROP := a \cdot n \cdot \left(\frac{WOB}{D_b}\right)^b = \left(5.658 \cdot 10^6\right)\ Pa \cdot \frac{m}{hr}$ — Rate of Penetration (m/hr)

$p := \frac{ROP}{60 \cdot n} = 166.77\ Pa \cdot mm$ — Pitch (Penetration Per Revolution)(mm)

Core Housing Calculations

Inputs:

$SS_{ys} := 169694 \cdot psi$ — 17-4 PH Stainless Steel Min. Yield

$SS_{UT} := 185068\ psi$ — 17-4 PH Stainless Steel Tensile Strength

$SS_{ysallow} := .4 \cdot SS_{ys} = \left(6.788 \cdot 10^4\right)\ psi$ — Shear Stress Allowable for SS

$F := 60 \cdot lbf$ — Applied Axial Force

$T := 28.7\ lbf \cdot ft$ — Torque Output from Drill

$ID := .66 \cdot in$ — Housing ID

$C_i := \frac{ID}{2} = 0.33\ in$ — Housing Inner Radius

$OD := .875 \cdot in$ — Housing OD

$C_o := \frac{OD}{2} = 0.438\ in$ — Housing Outer Radius

Torsion on Housing

$J := \frac{\pi}{2}\left(C_o^4 - C_i^4\right) = 0.039\ in^4$ CS Polar Moment of Inertia

$T_{max} := \frac{T \cdot C_o}{J} = \left(3.871 \cdot 10^3\right)\ psi$ Max Shear Stress In Shaft

$F.S := \frac{SS_{ysallow}}{T_{max}} = 17.533$ Shaft Safety Factor

Housing Bearing Capacity

$A_{housing} := \frac{\pi}{4} \cdot \left(OD^2 - ID^2\right) = 0.259\ in^2$

$\sigma_{Hbearing} := \frac{F}{A_{housing}} = 231.481\ psi$

$F.S := \frac{SS_{ys}}{\sigma_{Hbearing}} = 733.081$

Stabilizing Jig Calculations

Inputs:

$AL_{ys} := 40000 \cdot psi$ 6061 Aluminum Yield Strength

$AL_{ut} := 45000\ psi$ 6061 Aluminum Ultimate Tensile Strength

$SS_{ysallow} := .4 \cdot AL_{ys} = \left(1.6 \cdot 10^4\right)\ psi$ Shear Stress Allowable for 6061 Aluminum

$F := 60 \cdot lbf$ Applied Axial Force

$F_{spring} := 30 \cdot lbf$ Spring Force

$T := 344.4\ lbf \cdot in$ Torque Output from Drill

$\alpha := 15 \cdot deg$ Leg Angle

$J_{OD} := 2.125\ in$ Jig OD

$J_{ID} := 1.125 \cdot in$ Jig ID

$L_{OD} := 3.50\ in$ Leg Outside Diameter

$L_{ID} := 1.0625\ in$ Leg Inside Diameter

Torsion on Jig

$$J := \frac{\pi}{32}\left(J_{OD}{}^4 - J_{ID}{}^4\right) = 1.845\ in^4$$ Polar Moment of Inertia

$$T_{max} := \frac{T \cdot 1.75\ in}{J} = 326.735\ psi$$ Max Shear Stress On Jig

$$F.S := \frac{SS_{ysallow}}{T_{max}} = 48.969$$ Jig Safety Factor

Leg Bearing Capacity

$$A_{leg} := \frac{\pi}{4} \cdot \left(L_{OD}{}^2 - L_{ID}{}^2\right) = 8.734\ in^2$$ Area of legs

$$\sigma_{leg} := \frac{F}{A_{leg}} = 6.869\ psi$$ Stress on legs

$$F.S := \frac{AL_{ys}}{\sigma_{leg}} = 5.823 \cdot 10^3$$ Safety Factor of legs

Table F. 1 Material mechanical properties and strength

Mechanical Properties and Strength		
Grades >>	**SS316**	**17-4PH**
Tensile Strength Mpa	545	1276
Yield Strength Mpa	275	1170
Hardness (HB)	220	350
Elongation %	50%	8%

Appendix G – Timelines and Milestones (Semester 1)

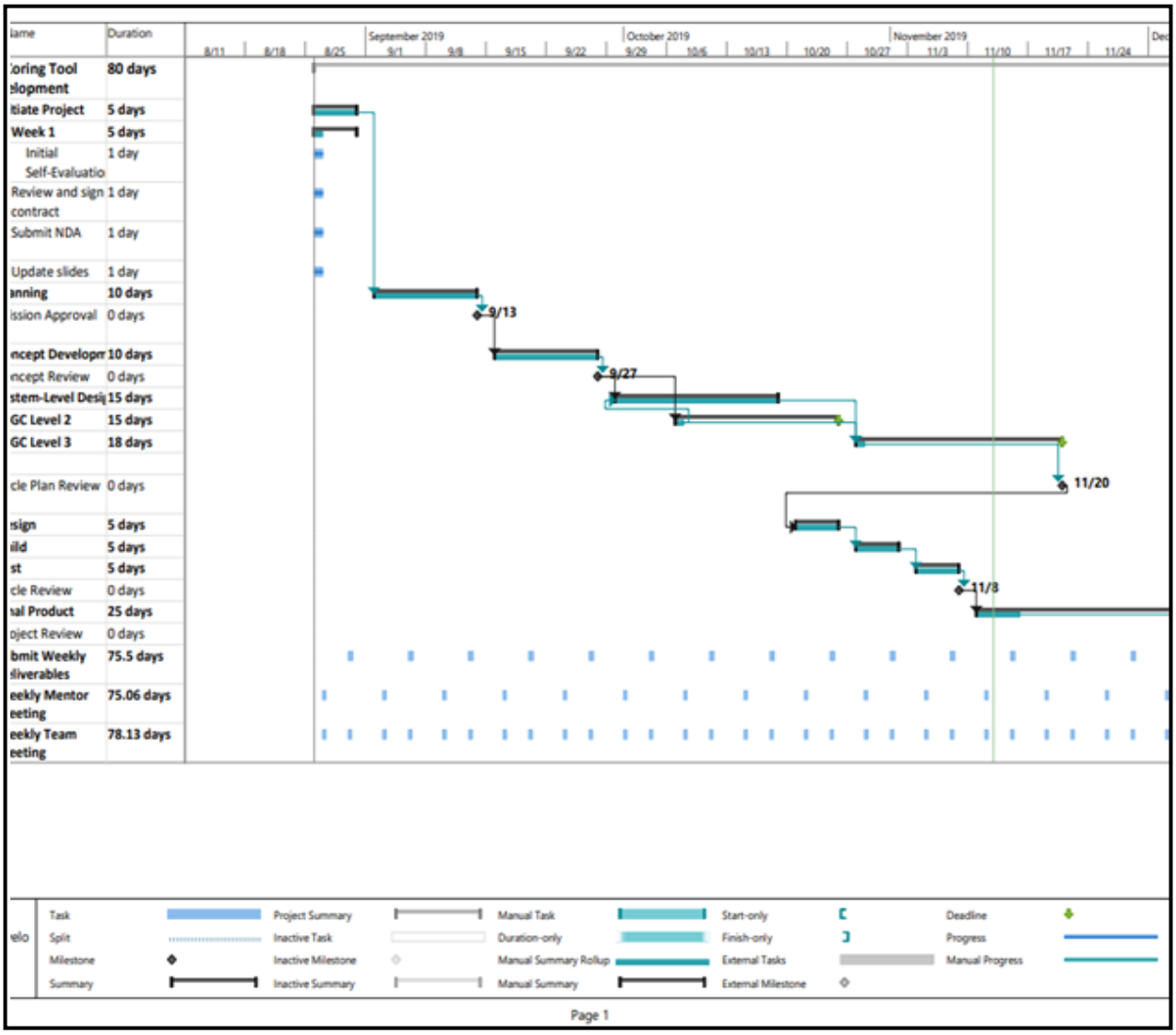


Figure G. 1 Semester-1 timeline and milestones

Appendix H - Timelines and Milestones (Semester 2)

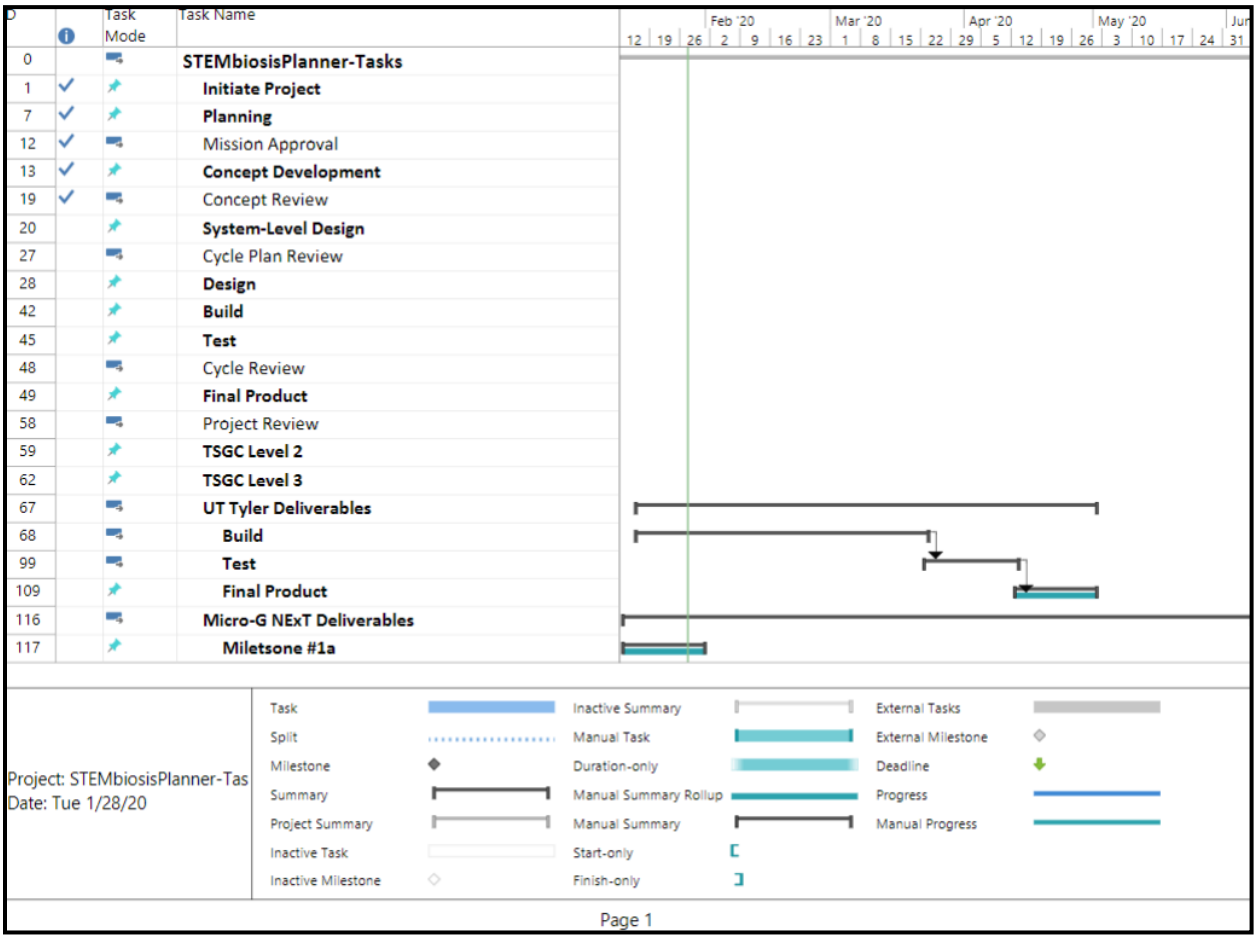


Figure H. 1 Semester-2 timeline and milestone

Appendix I – User Manual

I.1 Operations Plan

A procedure is required to successfully construct the core sampling device from its stored configuration and take a core sample. The operation procedure includes unpacking, setup, drilling, and sample extraction.

Unpacking procedure:

1. The user shall have the drill holstered on their person.
2. The user shall have the coring assembly completely stowed away.
3. The user shall open the stowed components. Upon opening the container, the user shall identify both the complete assembly of the stabilization jig and the coring tool, as well as the arbor mating mechanism.

Set up procedure:

4. The user shall remove the arbor mating mechanism and first install it on the top face of the coring bit.
5. The user shall do so by aligning the pins with the holes in the top face and then rotate the mechanism such that it screws into and is securely fitted to the top of the coring mechanism.
6. The user will then remove the completed assembly and attach it to the end of the drill. (At this point, the device is in the “ready configuration”) It is essential that, in doing so, the user keeps their hands away from the coring bit itself. With the coring assembly securely attached, the user can place the stabilization jig on the surface.
7. The user should always have one hand on the drill during its operation, and deployment.
8. Once the user is in a position where they can provide a downward force onto the assembly while operating the drill, the user is free to begin drilling into the surface.
9. During the operation of the drill, the user is to apply constant downward pressure until reaching depth. The user shall know they have reached depth by the visual markings on the coring assembly.

Drilling procedure:

10. If upon reaching depth, the user should stop applying additional downward force and continue allowing the drill to rotate for another 10 seconds. During this period, the user will need to keep the drill from rising due to a force exerted by the spring.
11. After this period, there should be enough clearance to sideload the drill and break away the sample. The sideloading procedure shall be to tilt the drill approximately 30° off parallel until the housing strikes the whole. At which point it is safe to remove the drill.
12. After sideloading, the user should reorient the drill perpendicular to the surface, then slowly pull up on the drill. This will allow the housing and the core sample to be withdrawn from the subsurface
13. Once on the surface, the user will be able to see clearance between the drill bit and the surface. Once clearance can be established between the surface and the drill bit it is safe to remove and reorient the device

Sample extraction:

14. The process for extracting the core sample shall be first to remove the assembly from the drill. This can be done by decoupling the core assembly from the drill.
15. After which the arbor mating mechanism should be exposed, and the user can place the core assembly (including the arbor) back on the surface.
16. The user can then remove the arbor mating mechanism allowing for a clear view of the mating hole. It is through this hole that the core sample can be extracted from the coring housing.
17. After the arbor mechanism is detached, it should be stowed away in its proper place. Upon doing so, the user can retrieve the dowel.
18. The user then can utilize a dowel to extend into the housing, pushing the core sample out the top face.

I.2 Safety

During the initial planning stages of the project, guidelines were created to ensure that the person assembling, testing, or handling the device would stay as safe as possible. Before gathering parts from manufacturing and the assembly/testing process beginning, observations were noted on what else would need to be included in the documentation. This includes material/chemical exposure, pinch points, and potential lacerations.

The following guidelines are set for personnel preparing test samples:

- Always wear proper personal protective equipment (PPE)
- Follow instructions for preparation of test samples thoroughly

The following guidelines are set for personnel assembling device:

- Always wear proper personal protective equipment
- Be mindful of pinch points while assembling device
- Be mindful of chemical interactions while assembling device
- Be mindful of sharp edges on carbide bits while assembling device

The following guidelines are set for personnel operating/testing device:

- Always wear proper personal protective equipment
- Be mindful of pinch points on the device
- Do not place hands directly below drill head
- Attach coring device to the drill chuck from only the top side of the device
- Be mindful of rotating parts while operating/testing device
- Operate a device with one hand

I.3 Parts listing

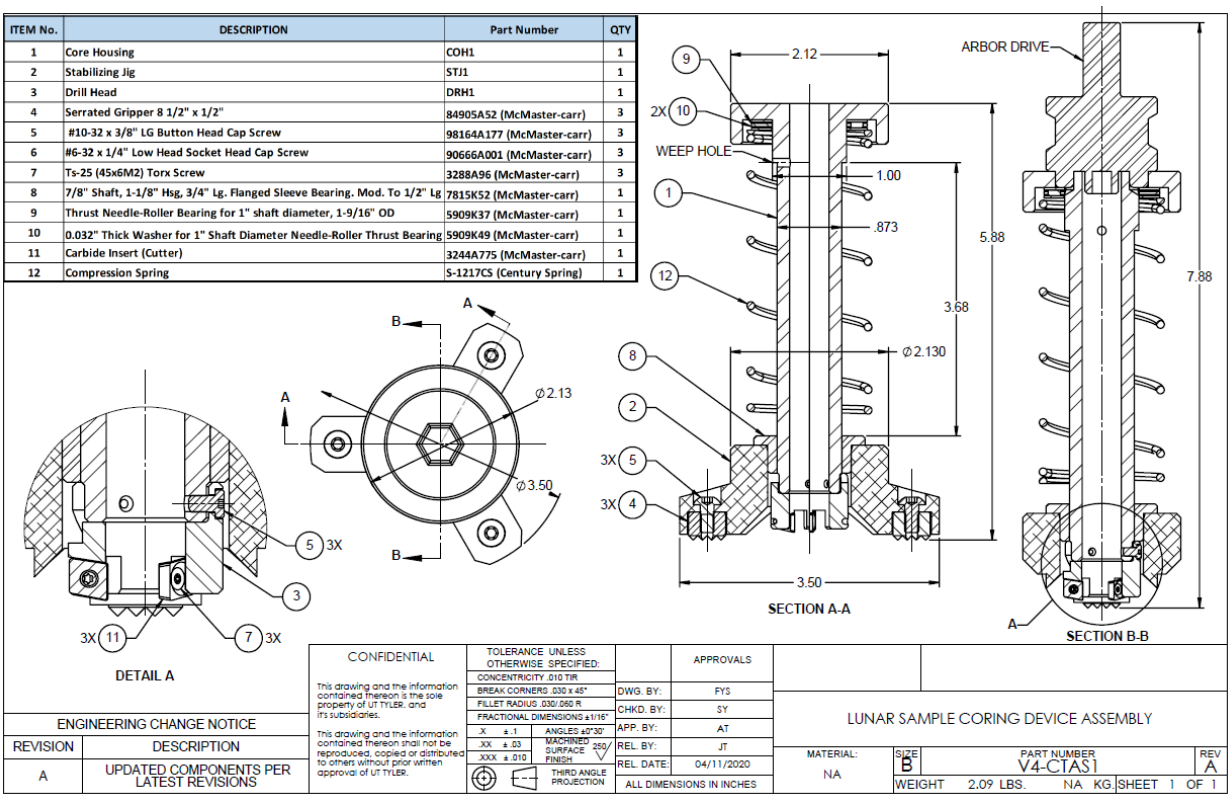


Figure I. 1 Assembly drawing with parts listing

Appendix J – Data Collection Hardware and Software

Table J. 1 Testing Data Collection Hardware and software

Component Name	**Purpose**	**Description**
Encoder	Linear position	BQLZR 600P/R Incremental Rotary Encoder DC5-24V Wide Voltage Power Supply 6mm Shaft
Load Cell	Force input	4pcs 50kg Half-bridge Load Cell Body Scale Weighting Sensor Amplifier+ 1pcs HX711 AD Weight Module Geekstory
Tachometer	RPM detection	EEEKit 4 Digital Red/Blue LED Tachometer RPM Speed Meter + Hall Proximity Switch Sensor NPN Led Panels Digital Led Module
Microcontroller	Microcontroller for data collection	Arduino MEGA 2560 REV3 [A000067]
Power Supply	External excitation source	5V 2.5A Power Supply, Wall Charger for Bose SoundLink Mini II, Micro, Revolve Plus, Color Bluetooth Speaker I II, QuietComfort 35, Raspberry Pi 2, Micro USB AC DC Adapter with On Off Switch



Figure J. 1 Incremental Encoder

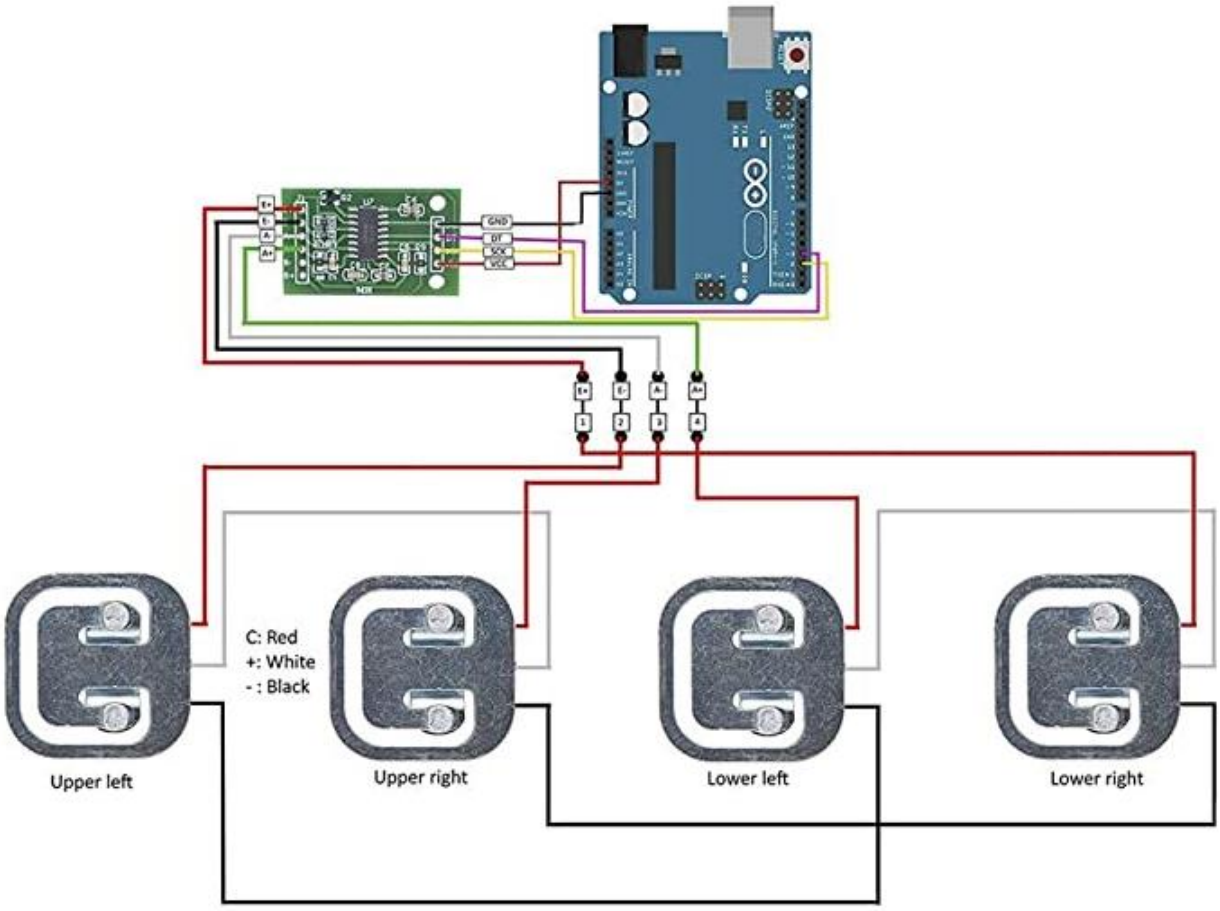


Figure J. 2 Load cell sensor



Figure J. 3 Hall Effect Tachometer



Figure J. 4 Arduino MEGA 2560



Figure J. 5 AC-DC Power Supply

Table J. 2 Data Collection Arduino Code

```
/*
Lunar sample coring tool data collection
 By: Shawn Yarbrough – Team STEMbiosis
*/
#include "HX711.h"
//This value is obtained using the SparkFun_HX711_Calibration sketch
#define calibration_factor -10890.0
#define DOUT  3
#define CLK  2
const int encoder_a = 20; // Green - pin 20 - Digital
const int encoder_b = 21; // White - pin 21 - Digital
long encoder = 0;
HX711 scale;
int hallsensor = 18; // Hall sensor at pin 2
volatile byte counter;
unsigned int rpm;
unsigned long passedtime;
void isr()
 {
   //Each rotation, this interrupt function is run twice, so take that into consideration for
   //calculating RPM
   //Update count
      counter++;
 }
 void setup() {
  Serial.begin(115200);
  scale.begin(DOUT, CLK);
//This value is obtained by using the SparkFun_HX711_Calibration sketch
  scale.set_scale(calibration_factor);
  scale.tare(); //Assuming there is no weight on the scale at start up, reset the scale to 0
  pinMode(encoder_a, INPUT_PULLUP);
  pinMode(encoder_b, INPUT_PULLUP);
    attachInterrupt(digitalPinToInterrupt(encoder_a), encoderPinChangeA, CHANGE);
  attachInterrupt(digitalPinToInterrupt(encoder_b), encoderPinChangeB, CHANGE);
  attachInterrupt(digitalPinToInterrupt(hallsensor), isr, RISING); //Interrupts are called on Rise
of Input
//Sets hallsensor as input
  pinMode(hallsensor, INPUT);
  counter = 0;
  rpm = 0;
  passedtime = 0; //Initialise the values
    Serial.println("LABEL,Date,Time,Timer,Position,Weight,RPM");
}
void loop() {
  float weight = scale.get_units();
```

```
//Interrupts are disabled
    detachInterrupt(digitalPinToInterrupt(hallsensor));
  rpm = 60000/(millis() - passedtime)*counter;
  passedtime = millis();
  counter = 0;
  //Restart the interrupt processing
  attachInterrupt(digitalPinToInterrupt(hallsensor), isr, RISING);
  Serial.println( (String) "DATA,DATE,TIME,TIMER," + encoder + "," + weight + "," + rpm);
  /*
  Serial.print(scale.get_units(), 3); //scale.get_units() returns a float
  Serial.print("\t");
  Serial.println(encoder);
  Serial.println();
  */
  delay(100);
}
void encoderPinChangeA() {
encoder += digitalRead(encoder_a) == digitalRead(encoder_b) ? -1 : 1;
}
void encoderPinChangeB() {
encoder += digitalRead(encoder_a) != digitalRead(encoder_b) ? -1 : 1;
}
```

Table J. 3 Load cell calibration

```
/*
 Example using the SparkFun HX711 breakout board with a scale
 By: Nathan Seidle
 SparkFun Electronics
 Date: November 19th, 2014
 License: This code is public domain but you buy me a beer if you use this and we meet someday (Beerware license).
 This is the calibration sketch. Use it to determine the calibration_factor that the main example uses. It also
 outputs the zero_factor useful for projects that have a permanent mass on the scale in between power cycles.
 Setup your scale and start the sketch WITHOUT a weight on the scale
 Once readings are displayed place the weight on the scale
 Press +/- or a/z to adjust the calibration_factor until the output readings match the known weight
 Use this calibration_factor on the example sketch
 This example assumes pounds (lbs). If you prefer kilograms, change the Serial.print(" lbs"); line to kg. The
 calibration factor will be significantly different but it will be linearly related to lbs (1 lbs = 0.453592 kg).
 Your calibration factor may be very positive or very negative. It all depends on the setup of your scale system
 and the direction the sensors deflect from zero state
 This example code uses bogde's excellent library:"https://github.com/bogde/HX711"
 bogde's library is released under a GNU GENERAL PUBLIC LICENSE
 Arduino pin 2 -> HX711 CLK
 3 -> DOUT
 5V -> VCC
 GND -> GND
 Most any pin on the Arduino Uno will be compatible with DOUT/CLK.
 The HX711 board can be powered from 2.7V to 5V so the Arduino 5V power should be fine.
*/
#include "HX711.h"
#define DOUT  3
#define CLK  2
HX711 scale;
//float calibration_factor = -7050; //-7050 worked for my 440lb max scale setup
float calibration_factor = -10890;
void setup() {
  Serial.begin(9600);
  Serial.println("HX711 calibration sketch");
  Serial.println("Remove all weight from scale");
```

```
  Serial.println("After readings begin, place known weight on scale");
  Serial.println("Press + or a to increase calibration factor");
  Serial.println("Press - or z to decrease calibration factor");
  scale.begin(DOUT, CLK);
  scale.set_scale();
  scale.tare(); //Reset the scale to 0
  long zero_factor = scale.read_average(); //Get a baseline reading
  Serial.print("Zero factor: "); //This can be used to remove the need to tare the scale. Useful in
permanent scale projects.
  Serial.println(zero_factor);
}
void loop() {
  scale.set_scale(calibration_factor); //Adjust to this calibration factor
  Serial.print("Reading: ");
  Serial.print(scale.get_units(), 2);
  Serial.print(" lbs"); //Change this to kg and re-adjust the calibration factor if you follow SI units
like a sane person
  Serial.print(" calibration_factor: ");
  Serial.print(calibration_factor);
  Serial.println();
  if(Serial.available())
  {
    char temp = Serial.read();
    if(temp == '+' || temp == 'a')
      calibration_factor += 10;
    else if(temp == '-' || temp == 'z')
      calibration_factor -= 10;
  }
}
```

Appendix K – Document Signoff

The University of Texas at TYLER
COLLEGE OF ENGINEERING

Department of Mechanical Engineering
Phone: +1.903.566.7003
Fax: +1.903.566.7148
Uttyler.edu/engineering

SENIOR DESIGN II – FINAL STATUS SHEET

TEAM: HEC 9 **Date:** 04/22/2020

Project final status:
COMPLETED: _____ **NOT COMPLETED:** ✓
ESTIMATED % Completion 90 **%**

Location on OneDrive where team project folder can be downloaded - See instructions after this table:
https://livepatriotsuttyler-my.sharepoint.com/:f:/g/personal/syarbrough5_patriots_uttyler_edu/EvrCswipS5dGvmoiA8v-iHgBmHCbtKXE1Sg-iWu62B6tPw?e=5xlzdq

PENDING ITEMS:

OUTSTANDING ITEMS ORDERED (BUT NOT RECEIVED)

Stabilization Jig is still with the manufacturer.

OUTSTANDING ITEMS NOT ORDERED

FINAL COMMENTS:

The team will be competing in September as apart of the Micro-G NExT challenge. The team will add to the current level of documentation by completing further testing through the summer. Initial testing proves extremely favorable however, further testing is warranted. The team may commission a small redesign of the Core Housing if testing indicates that such a change would be warranted. NASA mentor Kristine Davis is aware of such plans and has committed to stay on through summer with the entire team of the purposes of the competition. The team will submit all documentation and materials in August in accordance with the Micro-G NExT revised timeline.

SIGNATURE:

1.- Name: Samuel Najar **Signature:**
2.- Name: Shawn Yarbrough **Signature:**
3.- Name: John Tong **Signature:** John Tong
4.- Name: Andrew Tran **Signature:**
5.- Name: Flavio Santos **Signature:**
6.- Name: Yared Mulugeta **Signature:**
7.- Name: **Signature:**

Instructions for delivering all electronic files and documents related to the project:

1. MAKE SURE YOUR TEAM SHARES A FOLDER, and then mention where the folder is located in the table above. DO NOT MENTION or SEND A SHARE LINK. If any file is modified (files or folders added) after the link is sent, it will not be shared with the link owner.
2. **Main Folder Name:** HEC-XX Project [or TYL-xx Project] (XX = group number)
3. **Subfolders:**
    a. FINAL REPORT
    b. VIDEOS
    c. Software
    (MATLAB, MATHCAD, LABVIEW, ANSYS, FORTRAN, PYTHON, C++, FEA, CFD, etc.)
    d. IMAGES or PICTURES
    e. DRAWINGS (CAD, WORD, Any other)
    f. SPECIFICATIONS
    g. OLD DOCUMENTS: (old drawings, sketch, background, pictures, previous proto, previous designs, etc.)
4. **File names example:** HECXX – Final Report YYMMDD, or TYLXX – Final Report YYMMDD, where: (YY= Year, MM= Month, DD= Day)

The University of Texas at TYLER
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Senior Design Project II

MENG 4216 / EENG 4315

Project Lunar Coring Device Delivery and Acceptance

Senior design team STEMbiosis (HEC-9), from UT-Tyler College of Engineering, has worked with a sponsor: Kristine Davis to design, build and deliver the Lunar Coring Device as part of the senior students' academic work during the academic year of 2019-2020. This document includes the sign-off list and Kristine Davis final approval of the outcome of Lunar Coring Device delivered by Team STEMbiosis, based on the previously set and mutually-approved scope and specifications of the project. An authorized signature indicates this approval.

Table 1: Sponsor Sign OFF list for Deliverables of the Senior Project Lunar Coring Device

Item No.	Description of Deliverable	Comments:	Sponsor Sign Off: Authorized Initials
Lunar Coring Device	Core housing, Drill head, Stabilizing Jig.		Kristine Davis Digitally signed by Kristine Davis Date: 2020.04.24 20:19:57 -05'00'
Core Housing	Cylindrical Tube		Kristine Davis Digitally signed by Kristine Davis Date: 2020.04.24 20:10:53 -05'00'
Stabilizing Jig	Stabilizing Base	Currently with manufacturer.	Kristine Davis Digitally signed by Kristine Davis Date: 2020.04.24 20:11:14 -05'00'
Drill Head	Drill Head with Attachable Inserts		Kristine Davis Digitally signed by Kristine Davis Date: 2020.04.24 20:11:28 -05'00'
Stowed Configuration	Device Shall be contained within a 6" by 6" Cylinder		Kristine Davis Digitally signed by Kristine Davis Date: 2020.04.24 20:11:40 -05'00'
Weight	Device Shall be less than 3 lbs.	Total weight less than 2 lbs.	Kristine Davis Digitally signed by Kristine Davis Date: 2020.04.24 20:11:54 -05'00'
Device Interface	Device Shall not extend beyond the plane of drill chuck towards the driver		Kristine Davis Digitally signed by Kristine Davis Date: 2020.04.24 20:12:15 -05'00'
Device Power	Device Shall not be externally powered or pressurized		Kristine Davis Digitally signed by Kristine Davis Date: 2020.04.24 20:12:32 -05'00'

Operational Capacity	The device shall drill a core, capture the core, and contain the core when the drill is removed from the sample target.		Kristine Davis Digitally signed by Kristine Davis Date: 2020.04.24 20:12:46 -05'00'
Underwater compatibility	The device (all parts) shall operate underwater.	Limited testing completed.	Kristine Davis Digitally signed by Kristine Davis Date: 2020.04.24 20:12:58 -05'00'
Environmental Considerations I	The device shall be compatible with a chlorine water and a salt-water environment.	All materials are compatible.	Kristine Davis Digitally signed by Kristine Davis Date: 2020.04.24 20:13:31 -05'00'
Environmental Considerations II	The device shall operate within an environment from 23o F to 86o F (-5o C to 30o C).	All materials are compatible.	Kristine Davis Digitally signed by Kristine Davis Date: 2020.04.24 20:13:45 -05'00'
Production Model Documentation	Technical Documentation		Kristine Davis Digitally signed by Kristine Davis Date: 2020.04.24 20:19:44 -05'00'
B.O.M.	Bill of Materials		Kristine Davis Digitally signed by Kristine Davis Date: 2020.04.24 20:14:09 -05'00'
I.O.M.	Installation and Operations Manual		Kristine Davis Digitally signed by Kristine Davis Date: 2020.04.24 20:14:24 -05'00'
Assembly Drawings	Detailed Drawings		Kristine Davis Digitally signed by Kristine Davis Date: 2020.04.24 20:14:37 -05'00'
Testing	Testing of system		Kristine Davis Digitally signed by Kristine Davis Date: 2020.04.24 20:17:02 -05'00'
Test Phase 1	Validation of design	Initial results indicate the design is valid.	Kristine Davis Digitally signed by Kristine Davis Date: 2020.04.24 20:17:16 -05'00'
Completion Percentage			
Completion Claimed	90% Completion claimed.	Currently all parts have been manufactured only Stabilizing Jig is awaiting pickup	Kristine Davis Digitally signed by Kristine Davis Date: 2020.04.24 20:17:32 -05'00'
Delivery Date			
Delivery Date	The device and all relevant documentation will be submitted to Micro-G NExT before August 31st 2020	This is explicitly for the purposes of the Micro-G NExT Competition held in September 2020	Kristine Davis Digitally signed by Kristine Davis Date: 2020.04.24 20:17:54 -05'00'

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The following signatures indicate that all signees approve of the completion of this project and deliverables stated above which included all sponsor changes from original design and any consequent changes in the project, as mutually approved by all signing parties. Also indicated is the acknowledgement by all parties that the device and documentation will be submitted to Micro-G NExT with redundant documentation also submitted to University of Texas at Tyler.

For UT-Tyler Mechanical Engineering : Dr. Nael Barakat / Dr. Andres Garcia, etc.	Date: 4/27/2020
For UT-Tyler Mechanical Engineering : Samuel Ogletree	Date: 4/25/2020
For Kristine Davis: NASA *Senior Engineer*	Date: Kristine Davis Digitally signed by Kristine Davis Date: 2020.04.24 10:29:23 -05'00'
STEMbiosis Team member: Yared Mulugeta	Date: 04/24/2020
STEMbiosis Team member: Samuel Najar	Date: 04/24/2020
STEMbiosis Team member: Flavio Santos	Date: 04/24/2020
STEMbiosis Team member: John Tong	Date: 04/24/2020
STEMbiosis Team member: Andrew Tran	Date: 04/24/2020
STEMbiosis Team member: Shanwn Yarbrough	Date