NASA ROBOTIC MINING COMPETITION (RMC) LUNABOTICS 2021

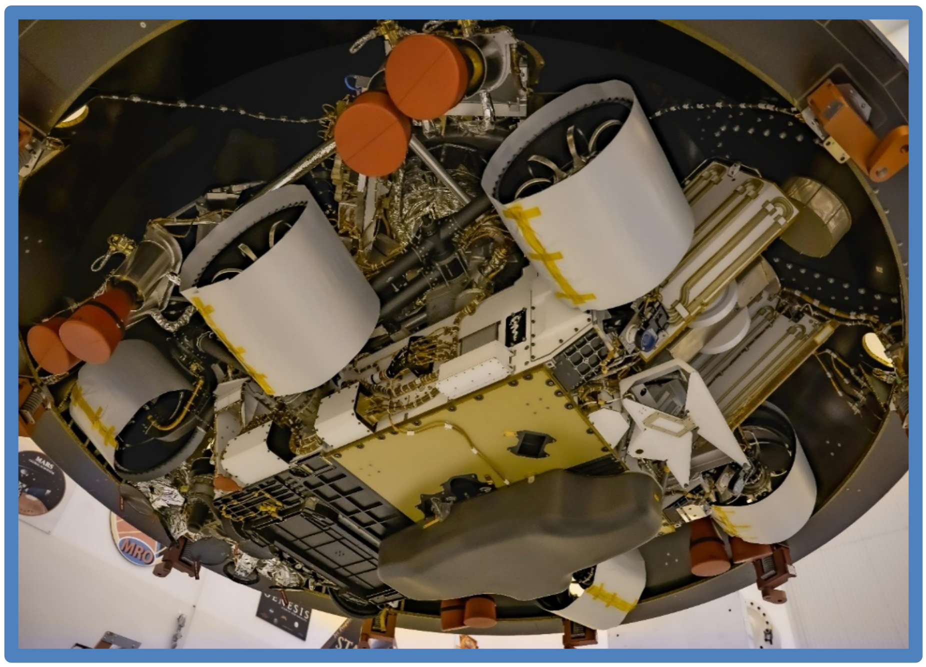
John F. Kennedy Space Center
Florida

SPECIAL STATEMENT

NASA has been closely monitoring developments of the COVID-19 outbreak. We are aware that many of the student teams participating in the seven Artemis Student Challenges must cope with limited or suspended physical access to campuses, travel restrictions or other impediments that may affect their ability to participate in the challenges as proposed.

Due to these hurdles we continue to face, and out of an abundance of caution for the teams and our workforce, activities for each of these events may look different than originally planned. It should be noted that the technical work completed by each team will not go unnoticed. Challenge managers for each activity will be in contact with participants on specifics and changes to the challenges, if any. We will continue to monitor the situation, and remain flexible and adapt as it evolves. Thank you for your patience and understanding.

NASA's Mars 2020 Perseverance



Perseverance rover is in position in the aeroshell that will protect the rover on its way to the Red Planet. To the right of the middle wheel is the plaque that commemorates the impact of the COVID-19 pandemic and pays tribute to the perseverance of healthcare workers around the world. Featuring a snake-entwined rod to symbolize healing and medicine, the plaque was attached to the rover in May 2020 at Kennedy Space Center in Florida. For more information about the mission, go to https://mars.nasa.gov/mars2020/

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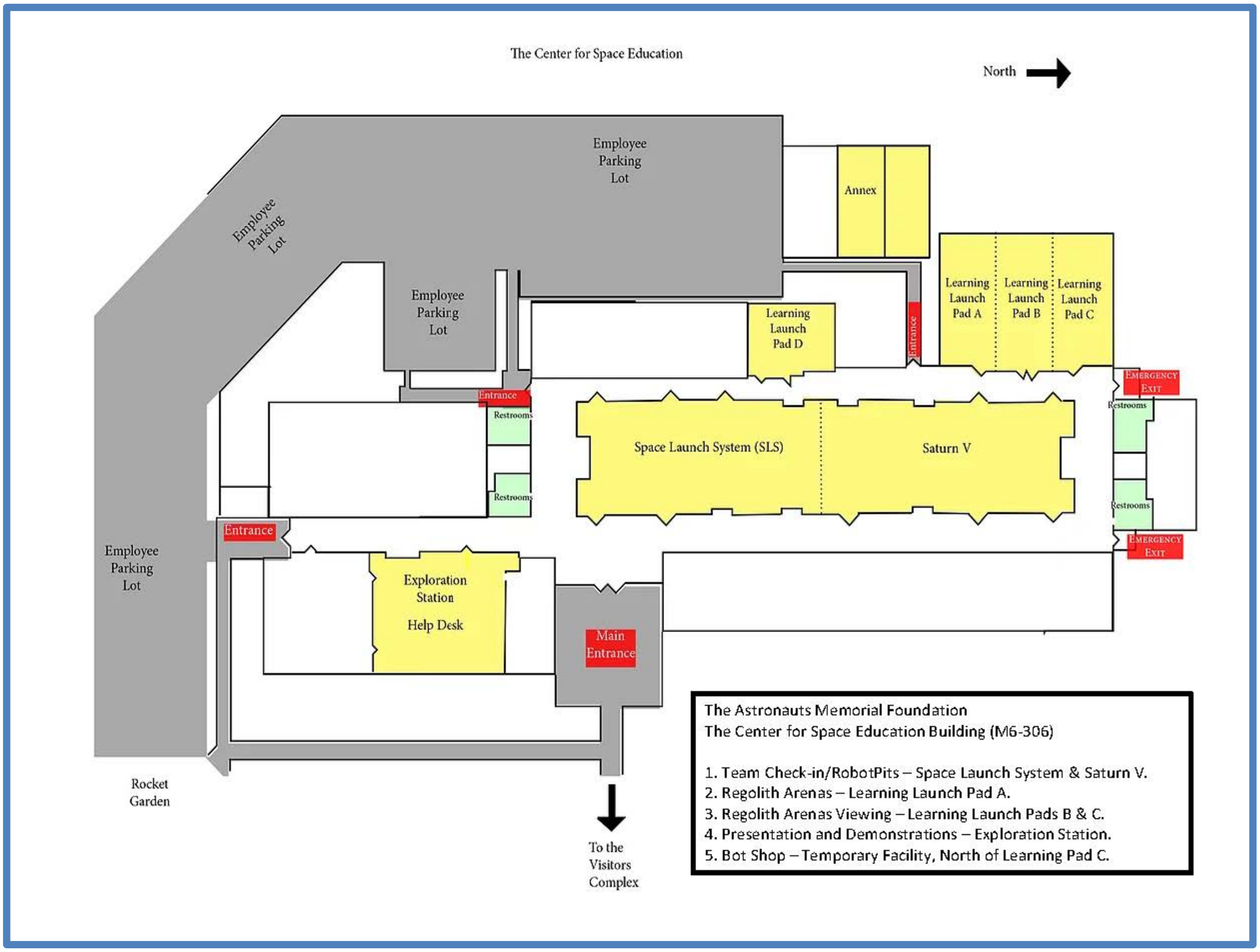


I. INTRODUCTION

1.1 THE NASA ROBOTIC MINING COMPETITION: LUNABOTICS CHALLENGE

Space Policy Directive 1

On December 11, 2017, the President of the United States signed Space Policy Directive 1, a change in national space policy that provides for a U.S.-led, integrated program with private sector partners for a human return to the Moon, followed by missions to Mars and beyond.

> *"NASA is called to land American astronauts, including the first woman and the next man, on the Moon by 2024. We're committed to achieving this bold goal. Through the Artemis program, we will go to the Moon in a way we have never gone before – with innovative new partnerships, technologies and systems to explore more of the lunar surface than ever before. Then we will use what we learn on the Moon to take the next giant leap – sending astronauts to Mars."*
>
> **-NASA Administrator Jim Bridenstine**

We will collaborate with our commercial and international partners and establish sustainable exploration. Then, we will use what we learn on and around the Moon to take the next giant leap—ending astronauts to Mars. Learn more at https://www.nasa.gov/what-is-artemis.

Rovers will carry a variety of instruments including ISRU experiments that will generate information on the availability and extraction of usable resources (e.g., oxygen and water). Advancing these technologies could enable the production of fuel, water, and/or oxygen from local materials, enabling sustainable surface operations with decreasing supply needs from Earth. Astronauts working on the lunar surface could test advanced robotics, as well as a wide set of new technologies identified in the Lunar Surface Innovation Initiative, focusing on development in areas including in-situ resource utilization (ISRU) and power systems.

The Robotic Mining Competition (RMC): Lunabotics

This Artemis Student Challenge is designed to train university students in the methods of NASA systems engineering while designing, building and operating an exciting lunar excavator prototype. In order to have a sustainable presence on the Moon, it will be necessary to excavate lunar regolith to extract local resources, so they don't have to be transported from Earth, through its deep gravity well.

The excavation technology needed will require tele-operation and various levels of autonomy. Each year the Lunabotics RMC competitors improve the designs of their excavation robots with better mechanical systems and improved sensors and autonomy software. Commercially available technology is constantly improving and the student teams take advantage of these capabilities to increase the level of autonomy. In addition, each year a new group of seniors enters the competition so that there is no redundancy or duplication in student engagement. The Lunabotics RMC has a competition model where the rules are evolving each year so that the infused technology is maximized and the student experience is enhanced with continuous improvement. Lunabotics is a college level event that supports the Artemis Moon to Mars mission requiring teams to participate in multiple events throughout the year and (if conditions allow) on-site at the competition. The goal of this Artemis challenge is to gather and evaluate excavator design and surface motion operational robotic data for future Lunar excavators.

The commercial cost of delivering payloads to the Moon is about $1.2 Million per kg (2019 estimate). This competition aims to simulate a Lunar mission where a robotic excavator is delivered to the Moon for regolith excavation operations. This corresponds to an approximate mission cost of $72 Million. Lower masses will result in lower mission costs so this competition rewards teams that have a lower robot mass.

The complexities of this Artemis Challenge includes the Project Management Plan, an Executive Summary, Vehicle Drawing(s), 3D CAD Modeling, One-Cycle Mining Animation, Public Outreach in a Cyber Learning Environment, the Systems Engineering Paper and Presenting and Demonstrating the entirety of the team's project and robot. The complexities of on-site mining include the abrasive characteristics of the regolith and icy-regolith simulants, the weight and size limitations of the Lunar mining robot and the ability to autonomously or tele-operate the robot from a remote Mission Control Center.

Tomorrow

NASA will directly benefit from the competition by encouraging the development of innovative robotic excavation concepts that may result in clever ideas and solutions. Our nation will need a future work force that has the skills for developing autonomous robotic mining on the Moon and other off-world locations. Advances in off-world mining have the potential to contribute to our nation's space vision and NASA's space exploration operations. Our nation will benefit by being leaders in a new space based economy. The systems engineering skills are valuable in other high technology industries that will add to the economic strength of our country. Good for NASA, Good for America, Good for All of Us.

1.2 CODE OF CONDUCT

RMC: Lunabotics is a National Aeronautics and Space Administration Artemis Challenge held in a professional, positive and safe environment. Competitors shall be courteous and respectful to all individuals. Competitors shall conduct themselves with integrity as to the spirit and intent of the rules and rubrics. Any violation of the "intent" of a rule is a violation of the rule itself. Teams (faculty advisor, students, etc.) not adhering to the Code of Conduct will be assessed penalty points. A second violation will result in disqualification of the team. Competitors shall use sound safety and engineering practices and principles at all times. Safety violations will result in disqualification of the team. The Project Manager and Head Judge's decision is final.

1.3 DISPUTES

The scoring decisions of the judges final. If the appeal process is chosen, the faculty advisor or the team leader shall submit the appeal in writing for consideration to the Project Manager or Head Judge in the scoring area before the last competition run of that day.

1.4 FREQUENTLY ASKED QUESTIONS (FAQS)

The FAQ document is revised as needed and is part of this document. It is the responsibility of the teams to read, understand, and abide by all of the Rules and Rubrics, FAQs, and any changes contained therein and to communicate with NASA's representatives and complete all surveys. When emailing documents, questions, etc., please make sure that your school name (not the team name) is in the subject of all emails. Faculty Advisors and Team Leads must identify themselves when sending questions on the Rules and Rubrics to ksc-robotic-mining-competition@mail.nasa.gov

1.5 CHANGES TO THE COMPETITION

There have been changes to the competition since it was held on-site at the Kennedy Space Center in 2018. Here are some of the changes:

1. The Robotic Mining Competition (RMC): Lunabotics is now a part of NASA's Artemis Student Challenges. Going forward to the Moon will be the shining moment of our generation. This moment will belong to you–the Artemis generation. Are you ready? See https://www.nasa.gov/stem/artemis.html

2. Lunabotics strongly encourages teams to collaborate with teams from schools classified as Minority Serving Institutions, see COLLABORATIONS.

3. When the Faculty advisor and/or Team Lead register at Team Registration, they can choose one of the two challenges for their team. Once the choice is made, there can be no changes. Teams can choose to be in either the "Design It Challenge" or the "Design It, Build It, Dig It Challenge", see RMC: LUNABOTICS CHALLENGES.

4. The robotic mining arena is located inside the Astronauts Memorial Foundation's Center for Space Education Building (M6-306), across the hall from the RoboPits.

5. Your off-world mining robots will be smaller and lighter than before, see LUNAR MINING ROBOT REQUIREMENTS & SAFETY.

6. The robotic mining arenas are smaller and shallower than before, see MINING ARENA INFORMATION.

7. Teams will be required to perform two official competition attempts (15 minutes each) to mine in the arena.

8. All deliverables are required unless otherwise stated as optional.

9. Submit all items through the website links, email submissions or copies are no longer acceptable. Do not wait until the deadline to submit.

10. Faculty Advisors and Team Leads - Communicate, Communicate, Communicate - when you have questions, concerns, etc. We cannot respond to requests from individual team members.

11. In the event the on-site mining competition cannot be held, the winners of the "Design It, Build It, Dig It Challenge" will be based on the teams with the highest total score from Phase I plus Phase II combined.

12. Statement of Rights of Use
    These two statements grant NASA, acting on behalf of the U.S. Government, rights to use the team's technical data and design concept, in part or in entirety, for government

purposes. This statement is not required. If choosing to include these statements, ALL team members and faculty advisors must sign. The statements read as follows:

As a team member for “ ____________” a team of undergraduate/graduate students from ________ university/college, 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 “_________” proposed by a team of undergraduate/graduate students from _________ university/college, 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.

The Indoor Mining Arena

II. COMPETITION DEADLINES

All items are due by 12:00 p.m. noon Eastern Time on the date listed below, failure to meet the deadlines will result in disqualification from the competition.

Deadlines		
Registration		
1	**Rules and Rubrics Released**	Tue Aug 11, 2020
2	**Team Registration Opens**	Wed Aug 19, 2020
	Labor Day (Federal Holiday)	**Mon Sep 07, 2020**
3	**Team Registration Closes**	Wed Sep 16, 2020
Lunabotics Phase I - Design It		
1	Submit Project Management Plan (required to advance to Phase II)	Wed Sep 30, 2020
2	Phase I Only Teams – Submit Team Biography and Photo w/Faculty	Wed Sep 30, 2020
	Columbus Day (Federal Holiday)	**Mon Oct 12, 2020**
3	Submit Executive Summary	Wed Oct 28, 2020
	Veterans Day (Federal Holiday)	**Wed Nov 11, 2020**
	Thanksgivings Day (Federal Holiday)	**Thu Nov 26, 2020**
4	Phase II Teams Announced	Dec 2020
Lunabotics Phase II - Build It (Jan-Apr)		
	New Year's Day (Federal Holiday)	**Fri Jan 01, 2021**
1	Public Outreach - Cyber-Learning Environment in place.	Wed Jan 13, 2021
	Martin Luther King Day (Federal Holiday)	**Mon Jan 18, 2021**
	President's Day (Federal Holiday)	**Mon Feb 15, 2021**
2	Submit Team Roster, Student Resume, Team Biography, Team Photo and Corrections to the NASA generated Team Roster	Wed Mar 03, 2021
3	Submit Final Team Roster	Mon Mar 29, 2021
4	Submit Systems Engineering Paper	Wed Apr 07, 2021
5	Submit Proof of Life - YouTube link, Submit Robot Photo (min. 1024 x 768 JPEG), Submit Supplementary Robot Data in Google Docs	Fri Apr 16, 2021
6	Submit Slide Presentation and Demonstration	

7	Submit Public Outreach Project Report	
Lunabotics Phase III - Dig It (May)		
1	Robot Vehicle and Communications Inspection	Mon May 17
2	Robot Practice Days	Mon-Tue May 17-18
3	Teams Present and Demonstration	Tues-Fri May 18-21
4	Opening Ceremony	Tue May 18
5	Robotic Mining Days	Wed-Fri May 19-21
6	Women in STEM Forum KSCVC Debus Center	Wed May 19
7	Awards Ceremony KSCVC Apollo-Saturn V Center	Fri May 21

III. REGISTRATION

3.1 ELIGIBILITY

Schools (post high school, vocational/technical schools, colleges and universities) located in the United States, its Commonwealths, territories and/or possessions are eligible to register for the Lunabotics competition. Collaborating schools must register is the same manner at the primary school they are collaborating with for the competition.

3.2 COLLABORATIONS

NASA collaborates with space agencies around the globe on many programs including the International Space Station, Earth observation missions and those headed to the Moon or Mars and other off-world destinations. Building and nurturing an eligible, diverse and inclusive workforce is imperative to the future success of NASA and to our Nation. Lunabotics strongly encourages registered teams to collaborate with teams (virtually, until conditions change) from schools classified as Minority Serving Institutions, vocational/technical schools, community colleges, etc. As an example, awards to winning collaborating teams would read as follows:

"Mars University" in collaboration with "Bending State University"

Decades of research by organizational scientists, psychologists, sociologists, economists and demographers show that socially diverse groups (that is, those with a diversity of age, race, ethnicity, gender and sexual orientation) are more innovative than homogeneous groups (*see Scientific American, dated 10.01.2014*).

1. MSI Capability Gateway
   https://msigateway.larc.nasa.gov/
2. Minority Serving Institutions (MSI's)
   www.doi.gov/pmb/eeo/doi-minority-serving-institutions-program.
3. Eligible MSI's
   https://www2.ed.gov/about/offices/list/ocr/edlite-minorityinst-list-tab.html
4. Scientific American
   https://www.scientificamerican.com/article/how-diversity-makes-us-smarter/

3.3 TEAM REQUIREMENTS

1. Students can be members of only one team.
2. Each team must have its own working robot(s).
3. Faculty advisor/staff/team lead must be registered with the school.
4. Team members must be cleared by NASA Security to attend this event.
5. Students must be currently enrolled and in good standing with the school.
6. The size of the team is at the discretion of the school, but the team must include at least two undergraduate students and no Ph.D. students.

3.4 REGISTRATION

Registration for Lunabotics is automated and electronically monitored. All teams must register via the site(s) provided and comply with all deadlines.

1. The Faculty Advisor or the assigned Team Lead will go to: www.secorstrategies.com/2021teamlunabotics to start the team registration process.
2. Teams can choose to participate in one of the two challenges for their team. At registration, teams must choose to compete in one of two challenges.

   "Design It Challenge" (Phase I)

   ~ OR ~

   "Design It, Build It, Dig It Challenge" (Phase I, Phase II, Phase III)

   If a team chooses this challenge, the 50 highest scoring teams from Phase I "Design It" (and not the "Design It Challenge") will be invited to the Phase II "Build It" challenge. Teams successfully completing all Phase II "Build It" requirements will be invited to the Phase III "Dig It" on-site challenge at the Kennedy Space Center in Florida to complete the challenge.

3. Once the choice has been made, there can be no changes. Teams can choose to be in either the "Design It Challenge" or the "Design It, Build It, Dig It Challenge", see 4.1 RMC: LUNABOTICS CHALLENGES.
4. After the team registration has closed, a notification will be sent with the website links and due dates to submit the faculty advisor and student registration forms.
5. Media Release Forms – Required for the "Design It, Build It, Dig It Challenge" teams. After the team registration has closed, a notification will be sent with the website links and due date to submit the Media Release Forms. Remember to send one email with all the team Media Release Forms. Media Release Forms are located here:

   NASA Media Release for Adults – (Do Not Use for Minors)
   NASA Media Release for Parent and Minor

IV. COMPETITION EVENTS

4.1 RMC: LUNABOTICS

At registration, teams must choose to compete in one of two challenges.

1) "Design It Challenge" (Phase I) ~ OR ~

2) "Design It, Build It, Dig It Challenge" (Phase I, Phase II, Phase III)

Please see the rubrics for a complete description of the deliverables. All deliverables are required unless otherwise stated.

4.2 PHASE I: DESIGN IT CHALLENGE

Teams will create and submit for evaluation the design for an autonomous or tele-operated (remote controlled) Lunar mining robot.

List of Deliverables:

1. Project Management Plan – see rubric.
2. Executive Summary – see rubric.
3. Presentation (Phase I only Teams) – see rubric.
4. Team Biography - limit is 200 words (Phase I only teams).
5. Team Photo w/ faculty (min. 1024 x 768 .jpeg) (Phase I only teams).
6. Bonus Points: Animation of the robot doing one competition mining cycle.

4.3 PHASE II: BUILD IT CHALLENGE

Teams will build their Phase I designed tele-operated (remote controlled) or autonomous Lunar mining robot during Phase II.

List of Deliverables:

1. Systems Engineering Paper (required) – see rubric.
2. Public Outreach Project Report (required) – see rubric.
3. Submit Slide Presentation and Demonstration (optional) – see rubric.
4. Submit Robot Data (required) – see data sheet at the end of this document. Provide information about your Lunar mining robot in Google Docs at: https://docs.google.com/forms/d/e/1FAIpQLSeB3v9iz1LoqPW2y1vLgLNlPGSW9Lt6nSRqU9jE3015Cq3C1A/viewform?usp=sf_linikk
5. Corrections to NASA generated Team Roster.
6. Final Team Roster – review and clearance by NASA Security will not allow changes after the posted date.
7. Submit all team NASA Media Release Forms in one email.
8. Submit Proof of Life on YouTube link – this is a video of your robot performing two mining cycles or 5 minutes of continuous operations
9. Team Biography – limit is 200 words.

10. Team Photo w/ faculty (min. 1024 x 768 .jpeg).
11. Student Resume (optional) – for NASA and event partners/sponsors.
12. Submit Robot Photo with School Name – (min. 1024 x 768 .jpeg), front, side and back of the robot.

4.4 PHASE III: DIG IT CHALLENGE

Teams successfully completing all Phase II “Build It” requirements will be invited to the Phase III “Dig It” on-site challenge at the Kennedy Space Center in Florida to complete the challenge, see, RUBRICS FOR PHASE III – MINING for more information.

V. RUBRICS FOR PHASE I

5.1 PHASE I – PROJECT MANAGEMENT PLAN (10 Points)

This is an initial plan. As you execute your project, things will change and your project will evolve, which is okay and expected. In your Systems Engineering Paper you can discuss the changes to your plan and how your project adapted. Maximum length of the plan is 5 pages. Any content over the 5 pages will not be judged.

The Project Management Plan is a required deliverable for teams to advance to Phase II.

Format: formatted professionally; organized clearly so that each required rubric element is easy to find; correct spelling; text no smaller than size 12 point font in the main body; text no smaller than size 9 point font in graphics and tables; using professional margins.

Scoring Rubric - Project Management Plan	
Element	**Points**
Initial Project Schedule Provide a Gantt Chart or equivalent that shows the project's major due dates and events to include at least the five items listed below. Discuss these only as needed. 1. Start Date 2. Completion Date: (after project decommissioning; this is the date when you have disposed of your robot system after the competition; e.g., you hand the system over to next year's team, etc.) 3. Major review milestones (as a minimum, these must include o Systems Requirements Review, o Preliminary Design Review, o Critical Design Review; o others may be identified as you find appropriate) 4. Competition product delivery dates to the Lunabotics Engineering Competition, including o delivery of Systems Engineering Paper, o the planned date to submit "Proof of Life" 5. Important milestones related to Project Cost Budget and Technical Performance Measurement budget as identified in the Initial Project Budget and Initial Technical Performance Measurement budget. Optionally, you may also identify any major Systems Engineering activities in your Initial Project Schedule.	**There are 3 points total for 6 elements**

6. Discuss how you will manage the evolution of the schedule during the life of the project (how often and when you will review project progress, and how you will adapt to schedule slips or schedule advance opportunities).	
Initial Project Cost Budget Provide an estimate of the total project cost, inclusive of all possible costs. Provide a Table of Major Budget Categories and Items including the following list items as a minimum. Discuss only as needed. 1. Breakdown of total project cost estimate for at least the following major items. (Total should add up to the estimate of the total project cost.) a. Cost estimates for elements in the earliest level System Hierarchy b. Labor costs, if any c. Material costs for competition (for production and completion of RMC deliverables) d. Travel costs to KSC 2. Critical scheduling milestones for budget items or other categories if any. [These should be reflected in item 5 for the Initial Project Schedule; e.g., dates funds will be needed, planned activities to raise funds, etc.] 3. Discuss how you will manage the evolution of the budget during the life of the project (how often you will review budget progress and when, and how you will adapt to budget shortfalls or possible cost savings should they occur).	**There are 3 points total for 3 elements**
Design Optimization Criteria Provide a short discussion, in the context of systems engineering, of what your team intends to optimize in your robot system design and operations (e.g., low mass, automation, collection of icy regolith simulant, low bandwidth, etc.)	**There is 1 point for 1 element**
Initial Technical Performance Measures (Technical Budgets) Provide Table of Technical Performance Measures that you deem are important to your design approach (e.g., mass, size, bandwidth, speed, etc.) including the following as a minimum. Discuss only as needed. 1. Identification of Technical Performance Measures 2. Initial Target for each Technical Performance Measure to be achieved by the competition	**There are 3 total points for 5 elements**

3. Allocation of each Technical Performance Measure across the elements of the earliest System Hierarchy (should sum up to the total) 4. Discuss any critical schedule milestones for achieving critical technical performance levels (e.g., decision points in the design process where if you are unable to achieve for example a certain total mass, you would change the design). [These should be reflected in item 5 for the Initial Project Schedule.] 5. Discuss how you will manage the evolution of the Technical Performance Measurement budgets during the life of the project (how often will review technical budget item progress, and how you will adapt to performance shortfalls should they occur).	

5.2 PHASE I – EXECUTIVE SUMMARY

Each team participating in Phase 1 of Lunabotics is required to submit an executive summary at the end of Phase 1. The executive summary should be clear and concise and include only the most relevant information regarding the team's design project. The executive summary should be written in such a way that someone unfamiliar with the project would be able to understand the purpose of your project and the final outcome. Please keep in mind the purpose of the executive summary is to give the reader a high-level view of your project. It should be able to stand-alone apart from a full report detailing your project.

Each team must submit an executive summary electronically in PDF by the deadline. A minimum score of 7 out of 10 possible points must be achieved to qualify to win in this category. This summary will contribute to the overall decision made by the judges as to which teams advance to Phase 2. The judges' decision is final. Teams who have selected to compete in Phase 1 only will be judged and scored independently from those teams who have selected to be eligible to compete in Phase 2. The Phase 1 ONLY team with the winning executive summary will receive a team plaque and individual certificates. Second and third place winners will receive certificates. Maximum length of the summary is 5 pages.

Scoring Rubric – Executive Summary	
Element	**Points**
Structure, Content and Intrinsic Merit: • Formatted professionally, clearly organized, correct grammar and spelling, size 12 font; single spaced, maximum of 1 page not including the cover. Appendices are allowed, however, and a link in the body of the report to a multimedia site with additional photos or videos is allowed. Cover page must include: team name, title of paper, full names of all team members, university name and faculty advisor's full name. • Purpose for this design project. • Illustrations must appropriately demonstrate the design project.	There are 3 points for 3 elements.

Technical Merit: • Executive summary precisely summarizes the design project in a concise manner. • Team's design and problem statement are effectively described. The team must address what problem the team is solving and how this problem contributes to NASA's Artemis mission. • List of the design team's primary goals, how did you achieve them. • Final conclusions are clear	There are 4 points for 4 elements.
Appendix: • Link to the 3-D CAD model. • Designs of the Lunabot - Isometric view, top view of the design, side view of the design, overall dimensions, parts list and wireframe (if possible). Link to animation if team has elected to add animation.	There are 2 points for 2 elements. A bonus point may be awarded for animation.

5.3 PHASE I – PRESENTATION

TO BE ADDED

VI. RUBRICS FOR PHASE II

6.1 PHASE II – SYSTEMS ENGINEERING PAPER (25 POINTS)

Each team must submit a Systems Engineering Paper electronically as a PDF. The purpose of the Systems Engineering Paper is for the team to demonstrate how they used the systems engineering process in designing, building and testing their robot.

All required elements of the rubric must be discussed in the main body of the paper; you may reference the appendix and provide *supporting* information there. A minimum score of 20 out of 25 possible points must be achieved to qualify to win in this category. In the case of a tie, the judges will choose the winning Systems Engineering Paper. The judges' decision is final. For reference, undergraduate course materials in NASA Systems Engineering are available at www.spacese.spacegrant.org.

Scoring Rubric - Systems Engineering Paper	
Element	**Points**
Content 1. Format: The Systems Engineering Paper shall be formatted professionally as if for submission to a professional journal: organized clearly so that each required rubric element is easy to find; with correct grammar and spelling; with text no smaller than size 12 point font in the main body and appendices; text no smaller than size 9 point font in graphics and tables; using professional journal margins; single spaced; and, consist of a maximum of 20 pages in the main body not including the cover page, title page, table of contents, and references pages. Up to five additional pages of appendices shall be allowed and shall be referenced and discussed in the main body. Only the first 20 pages of the main body and the first five pages of appendices will be subject to judging. The cover page must include: team name, title of paper, full names of all team members, university name, and faculty advisor's full name. 2. Faculty Signature: The cover or title page shall include the signature of the sponsoring faculty advisor and a statement that he/she has read and reviewed the paper prior to submission to NASA. 3. Reason for using Systems Engineering: A statement shall be included early in the main body explaining the reason	**There are 3 points for 3 elements, one point each**

the team used systems engineering in the NASA Lunabotics Engineering Competition (beyond that it is required). (e.g. What benefit did it provide? How was systems engineering valuable to your project?)	
Project Management Merit 1. Design Optimization Criteria: In the context of systems engineering; discuss what your team intends to optimize in your robot system design and operations (light weight? automation? collection of icy regolith simulant? low bandwidth? etc.) *(one point)* 2. New Design or Design Update: Clearly identify the new elements in this competition year's robot system (either state that the robot system is an entirely new design, or identify the specific subsystems or components that were changed on a previous robot system). Explain how you arrived at your decision for these changes to a previous design. Focus the rest of the paper on the systems engineering work you performed to develop the new/updated subsystems/components and incorporate them into the whole system to perform the mission. *(two points)* 3. Major reviews: At a minimum, descriptions of how the System Requirements Review (SRR), Preliminary Design Review (PDR), and Critical Design Review (CDR) were conducted, and how the system design and project plans changed as a result of external reviewers' comments. *(three points)* 4. Schedule of work: Discuss the project schedule and its evolution from inception to disposal of robot system (original planned schedule before project start: actual schedule performance with schedule changes tracked against the original schedule, reported as a minimum at major reviews). Demonstrate in the discussion that the schedule was used to manage the project. *(one point)* 5. Cost budget: Discuss the budget and its evolution for total project costs including travel; estimated predicted costs before project start, with actual costs tracked against estimated, reported as a minimum at major reviews as the project matures. *(one point)*	**8 points for 5 elements.** **2 bonus points may be awarded for exceptional work on Project Management Merit elements**
Systems Engineering Merit 1. Concept of operations (Describe how the robot system elements at each system hierarchy level will be operated	**8 points for 8 elements, one for each element.** **Up to 4 additional points for exceptional work and**

under the environmental conditions of the competition to accomplish the robot system mission). 2. System hierarchy (A top-down breakdown of the system design; the elements across each level in the hierarchy should be the central topic reviewed and baselined at each control gate or major review). 3. Interfaces (Identify key interfaces between system elements in the system hierarchy at each system hierarchy level, including external interfaces). 4. Requirements (Identify the key driving requirements for robot system design, operations, interfaces, testing, safety, reliability, etc., stated in proper “shall” language. Address system and lower level requirements. These are the requirements that should be addressed when you discuss verification). 5. Technical Performance Measurement (Identify and discuss technical measures that are important to achieving your Design Optimization Criteria (e.g., mass, power, data, etc.), how they are allocated initially to system elements in the system hierarchy, how they are tracked against the initial allocation reported as a minimum at each subsequent major review as the system matures through verification. Demonstrate the budgeting and management of these important technical quantities throughout the design process). 6. Trade Studies (Discuss how important robot system decisions were made using a trade study methodology, with key decision results captured as robot system derived requirements). 7. Reliability (Discuss design and operations considerations for assuring safety in the event of a system component failure during operations (captured as key driving requirements), and design and operations considerations for assuring successful completion of the competition without a failure). 8. Verification of system meeting requirements (Discuss how you assure or intend to assure that the as built system satisfies, in the context of the concept of operations and under the environmental conditions of the competition, all of the key driving requirements identified and discussed in the paper).	**additional SE methods used.**

6.2 PHASE II – SLIDE PRESENTATION AND DEMONSTRATION (25 POINTS, OPTIONAL)

The Slide Presentation and Demonstration is an optional category in the overall competition and will be judged by a panel of NASA and private industry personnel. Each team will be allotted 25 minutes in front of the judging panel. It is expected that the presentation and demonstration will last approximately 20 minutes with an additional 5 minutes for questions and answers. There is a hard cut-off at the 25 minute mark in order to maintain the judging schedule.

The slides for the presentation must be submitted electronically in PDF file format prior to the deadline. NASA will project these slides onto the screen during the presentation. Please note that updates and modification to slides are not possible after the deadline, as judges will pre-score the content. Visual aids, such as videos and handouts, may be used during the presentation. Teams are responsible to bring their own display equipment (laptop, phone, tablet, etc.) for video playback.

Each subcomponent of the Scoring Elements will be ranked using an adjective rating system, with an “Excellent” score receiving full credit, “Very Good” receiving 70% credit, “Satisfactory” receiving 50% credit, “Marginal” receiving 20% credit, and “Unsatisfactory” receiving 0% credit. The “Excellent” rating is used to account for exceptional work (there are no bonus points this year). In case of a tie, the judges will choose the winning presentation. The judges’ decision is final.

Notes on Demonstration

1. Safety is of the utmost importance. You are expected to be aware of the specific hazards associated with your robot and plan safe practices for demonstration. Everyone shall adhere to safe practices at all times during the demonstration, especially when troubleshooting unexpected issues in real-time. A clear zone shall be established around the robot, and no one shall enter that zone while the robot is in operation. All content from this paragraph shall be addressed when presenting the “Safety plan” topic.

2. “Demonstration” defined: We prefer that you perform a live demonstration of all functions via the control system, however we recognize that this is not always possible. If parts or the entire robot cannot be controlled at the time of demonstration, it is acceptable to move parts by hand (once the power has been turned off), show video from practice runs, etc. to communicate the functionality and attributes of the system and/or subsystems.
3. In the presentation room: The competition staff will display the presentation as submitted (see “Dates & Deadlines”); and will provide you with a remote control. An area will be set aside to set up your robot for demonstration. Note: you must move the robot from the cart to support stands if the tracks/ wheels will be operated during the demonstration. Teams may either use the provided supports or bring their own.

4. Safety: Re-read the above note on safety, and plan how to safely handle the unexpected!

<table>
<tr><th colspan="2">Scoring Rubric – Slide Presentation and Demonstration</th></tr>
<tr><th>Element</th><th>Points</th></tr>
<tr><td>Scoring Element 1: Individual Slides

1. Judging Criteria
a. Content, Formatting, and Illustrations: Each topic is addressed in sufficient depth. Include illustrations to support slide content (technical content, progression of the project, etc.). Ensure that formatting is readable and there is a good balance of text to graphics. Utilize proper grammar and spelling.
b. Presenter’s Delivery: Body language, preparedness, slide handling, knowledgeable, passion, effective communication.

2. Topics to Cover
a. Introduction
i. Include team name, university name, names of team members, and faculty advisor’s name.
b. Safety Plan
i. Robot-Specific Details: Discuss hazards and safety features.
ii. Demonstration Safety: Discuss your plan for the demonstration. Include hazards that could be encountered during the demonstration and how you have addressed them to ensure a safe demonstration.
c. Project and System Performance Goals
i. Qualitative
ii. Quantitative: Specify target values/ ranges
d. Project Management – Management of budget, schedule, team, risk, etc.
e.) Design and Testing
i. General Philosophy and Process
ii. System-level Alternatives Considered
iii. Subsystem Alternative Analysis and Design Development (Mining, Mechanical, Electrical, Software and Controls)
iv. Final Configuration
v. Performance Testing (include comparison of testing results to goals)
f.) Innovation
i. Comparison to last year and evolution from previous years
ii. Identify efforts to evolve processes, features, components, etc.</td><td>There are 15 base points for this element.

Lack of “innovation” topic coverage will not count against teams in their first year at the competition.</td></tr>
<tr><td>Scoring Element 2: Overall Package</td><td></td></tr>
</table>

1. General organization and flow of the slides as a package 2. General organization and flow between presenters. Time management: appropriate number of slides and material for time allotted and a professional cadence. 3. Question and Answer session 4. Overall Performance	**There are 6 base points for this element.**
Scoring Element 3: Demonstration Live demonstration will not be permitted if the “Demonstration Safety” component of the Safety Plan was not addressed prior to the intended movements. Scoring: 1. Pass/Fail criteria: a. Adherence to the safety plan. b. Executing the demonstration safely. 2. Extent of organization, integration, and planning 3. Extent of demonstration 4. Depth of explanation	**There are 4 base points for this element.** **Failure to adhere to safe practices will automatically result in a score of “0” points.**

6.3 PHASE II - PUBLIC OUTREACH PROJECT REPORT (20 POINTS)

Each team must participate in an educational outreach project in their local community to engage students in STEM (Science, Technology, Engineering and Math). We are returning to the moon as a new generation of explorers, this time to stay. Outreach activities should capitalize on the excitement of NASA’s Artemis program to spark student interest and involvement in STEM and to create enthusiasm as we prepare for humanity’s next giant leap, sending humans to mars. Outreach strategies may include lessons and classroom materials using emerging communications and educational technologies to promote STEM; hands-on science and engineering activities that draw on NASA’s unique missions; and community demonstrations that have a hands-on component involving K-12 students. Teams are encouraged to connect with a diverse student population including women, minorities and persons with disabilities.

A minimum 50% of outreach conducted must be done virtually.

Each team must submit a report of the Outreach Project electronically in PDF by the deadline. A minimum score of 11 out of 15 possible points must be achieved to qualify to win in this category. In the case of a tie, the judges will choose the winning outreach project. The judges’ decision is final.

Scoring Rubric – Public Outreach Project Report	
Element	**Points**
Structure, Content and Intrinsic Merit: 1. Formatted professionally, clearly organized, correct grammar and spelling, size 12 font; single-spaced, maximum of 5 pages not including the cover. Appendices are not allowed, however, a link in the body of the report to a multimedia site with additional photos or videos is allowed. Cover page must include: team name, title of paper, full names of all team members, university name and faculty advisor's full name. 2. Purpose for this outreach project, identify outreach recipient group(s). 3. Illustrations must appropriately demonstrate the outreach project.	**There are 3 points for 3 elements.**
Educational Outreach Merit: 1. The report must effectively describe what the outreach activity(s) was. 2. The report must describe exactly how the Lunabotics Competition team participated, including the number of team members present and the number of hours each team member participated. 3. The report must reflect how the outreach project inspired others to learn about robotics and engineering. The outreach must be STEM focused. 4. The report must demonstrate the quality of the outreach including how hands-on activities were used to engage the audience at their level of understanding in outreach activities. 5. The report must reflect how the team created a cyber-learning network to inspire others virtually to learn about robotics and engineering. The outreach must be STEM focused and include a hands-on component students could easily do at home or in a classroom. 6. Develop three quality activities for K-12 classrooms to participate in your virtual STEM experience. One activity for each of the following grade levels; K-4, 5-8, 9-12. 7. Activities must relate in some way to the Lunabotics Competition. 8. The report must demonstrate the quality of the outreach including how hands-on activities were used to engage the audience at their level of understanding. How are you creating dialog between yourself and the school to	**There are 9 points for 9 elements.**

encourage the students to pursue STEM? Are you providing teachers the tools they need to reinforce your projects? 9. The report must show statistics on the participants. How many children did you reach? What age range/grade-level? Female/male students? For your cyber-learning network, how far did you reach (number of states, etc.)? EACH EVENT NEEDS STATISTICS. The report must contain a table for both virtual and in person events, that includes each event, age/grade level, and number reached.	
Additional points for exceptional work: 1. The report must clearly describe activities, processes, and milestones used to engage underserved and underrepresented populations. 2. The report must reflect how the outreach project informed students of NASA's Artemis program and engaged them in understanding that they are the Artemis generation. 3. Using survey methodology, the report must provide data on the demographic, geographic, and participant's perception of the outreach project. The report must show how you used engineering to improve/enhance either the experience of those you worked with or some aspect of your community.	**There are 3 points for 3 elements.**

VII. RUBRICS FOR PHASE III - MINING

7.1 THE MINING CATEGORY (25 POINTS)

Off-world mining requires teams to consider a number of design and operation factors such as high robot dust tolerance and minimizing dust projection, efficient communications, minimizing vehicle mass, minimizing energy/power required, and maximize autonomy. In each of the two official competition attempts, the teams will score cumulative mining points. The teams with the first, second and third most mining points averaged from both attempts will receive 25, 20 and 15 points, respectively**.** Teams not winning first, second or third place in the mining category can earn one bonus point for each 0.5 kilogram of rock/gravel mined and deposited up to a maximum average of ten points. All decisions by the judges are final.

7.2 SCORING FOR THE MINING CATEGORY

Mining Points Calculator				
Mining Category Elements	**Units**	**Specific Points**	**Example Actuals**	**Example Mining Points**
1. ***Pass All Inspections (Comm/Vehicle)***.	1,000=Pass / 0=Fail	0 or 1,000	1,000.00	**1000.00**
2. ***Gravel Mined*** - The rock/gravel will be sieved out at the collector bin and weighed separately from the BP-1. During each competition attempt, the team will earn 10 mining points for each kilogram in excess of 1.0 kg of rock/gravel (ex: 11 kg of gravel mined will earn 100 mining points).	kg	10.00	11.00	**100.00**
3. ***Average Data Bandwidth Use*** - During each competition attempt, the team will lose one (1) mining point for each 50 kilobits/second (kb/s) of average data used (-1/50kb/sec).	Kbps/sec	-0.02	1066.00	**-21.32**
4. ***Camera bandwidth Use*** - During each competition attempt, the team will lose 200 pts for each situational awareness camera used (camera and width usage 200 kb/camera).	Kpbs/camera	-200.00	400.00	**-8.00**
5. ***Mining Robot Mass*** - During each competition attempt, the team will lose 8 Mining points for each kilogram of total mining robot mass. (For example, a mining robot that weighs 60 kg will lose 480 Mining points)(-8/kg).	kg	-8.00	60.00	**-480.00**
6. ***Report Energy Consumed*** - During each competition attempt, the team will lose one (1) Mining point for each watt-	watt-hour	-1.00	9.00	**-9.00**

hour of energy consumed. The electrical energy consumed must be displayed by an (commercial off the shelf or "COTS") electronic data logger and verified by a judge (-1/watt-hour).				
7. ***Dust Tolerant Design* -** Based on judge's decision, 3 items (30 points max).	Judge's Decision (JD)	0 to 30.00	30.00	**30.00**
8. ***Dust Free Operation*** - Based on judge's decision, 3 items (70 points max).	Judge's Decision (JD)	0 to 70.00	70.00	**70.00**
9. *Autonomy* - See Mining Points - Autonomy	task	50, 150, 300 or 500	150.00	**150.00**
10. *Total Points*				**831.68**

7.3 MINING POINTS – MINING

1. Each team will earn 1000 Mining points after passing the safety inspection and communications check.

2. During each competition attempt, the team will earn 10 Mining points for each kilogram in excess of 1.0 kg of rock/gravel deposited in the collector bin. (For example, 11 kg of gravel mined will earn 100 Mining points.) The rock/gravel will be sieved out at the collector bin and weighed separately from the BP-1.

3. During each competition attempt, the team will lose one (1) mining point for each 50 kilobits/second (kb/s) of average data used.

4. During each competition attempt, the team will lose 200 points for each situational awareness camera used (Camera Bandwidth Usage 200 kb/camera).

5. During each competition attempt, the team will lose 8 Mining points for each kilogram of total mining robot mass. (For example, a mining robot that weighs 60 kg will lose 480 Mining points).

6. During each competition attempt, the team will lose one (1) Mining point for each watt-hour of energy consumed. The electrical energy consumed must be displayed by an (commercial off the shelf or "COTS") electronic power data logger and verified by a judge.

7. During each competition attempt, a team can earn up to 30 Mining points for dust tolerant design features on the mining robot. Teams are encouraged to point out dust tolerant and dust free features to the judges during setup. The judges will allocate these points based on an inspection.

8. During each competition attempt, a team can earn up to 70 Mining Points for dust free operation. The judges will allocate these points based on actual performance during the competition attempts. If the mining robot has exposed mechanisms where dust could accumulate during a lunar mission and degrade the performance or lifetime of the mechanisms, then fewer Mining points will be earned in this category. If the mining robot raises a substantial amount of airborne dust or projects it due to its operations, fewer mining points will be earned. Ideally, the mining robot will operate in a clean manner without dust

projection, and all mechanisms and moving parts will be protected from dust intrusion. The mining robot will not be penalized for airborne dust while dumping into the collector bin. All decisions by the judges regarding dust tolerance and dust projection are final.)

9. DUST-TOLERANT DESIGN
The 30 points for dust-tolerant design will be broken down as follows:

a. Drive train and components enclosed/protected: 10 points
b. Active dust control (brushing, electrostatics, etc.): 10 points
c. Custom dust sealing features (bellows, seals, etc.): 10 points

10. DUST-FREE OPERATION
During each competition attempt, a team can earn up to 70 Mining Points for dust free operation. The judges will allocate these points based on actual performance during the competition attempts. (If the mining robot has exposed mechanisms where dust could accumulate during a lunar mission and degrade the performance or lifetime of the mechanisms, then fewer Mining points will be earned in this category. If the mining robot raises a substantial amount of airborne dust or projects it due to its operations, fewer mining points will be earned. Ideally, the mining robot will operate in a clean manner without dust projection, and all mechanisms and moving parts will be protected from dust intrusion. The mining robot will not be penalized for airborne dust while dumping into the collector bin. All decisions by the judges regarding dust tolerance and dust projection are final.

The 70 points for dust-free operation will be broken down as follows:

a. Driving without dusting up crushed basalt (20 points)
b. Digging without dusting up crushed basalt (30 points)
c. Transferring crushed basalt without dumping the crushed basalt on your own robot or around the collection bin (20 points)

7.4 MINING POINTS – COMMUNICATIONS

1. Each team is required to command and monitor their mining robot over the NASA provided network infrastructure.

2. This configuration must be used for teams to communicate with their robot.

3. The “Lander” camera is staged in the Mining Arena. Lander Control Joystick and camera display will be located with the team in the Mission Control Center (MCC).

4. The MCC will have an official timing display. The excavated mass will be displayed after the end of the competition run.

5. Handheld radios will be provided to each team to link their Mission Control Center team members with their corresponding team members in the mining arena during setup.

6. Each team will provide the wireless link (access point, bridge, or wireless device) to their mining robot, which means that each team will bring their own Wi-Fi equipment/router and any required power conversion devices. Teams must set their own network IP addresses to enable communication between their mining robot and their control computers, through their own wireless link hosted in the Mining arena.

7. In the mining arena, NASA will provide an elevated network drop (male RJ-45 Ethernet plug) that extends to the Mission Control Center, where NASA will provide a network switch for the teams to plug in their laptops.

    a. The network drop in the Mining arena will be elevated high enough above the edge of the regolith bed wall to provide adequate radio frequency visibility of the Mining arena
    b. A shelf will be set up next to the network drop at a height 0 to .5 meter above the walls of the arena, and will be placed in a corner area on the same side as the collection bin. During robot system operations during the competition, there may be some dust accumulation in this area. This shelf is where teams will place their Wireless Access Point (WAP) to communicate with their mining robot.
    c. Teams are strongly encouraged to develop a dust protection cover for their wireless access point (WAP) that does not interfere with the radiofrequency signal performance.
    d. The WAP shelves for side A and side B of the Mining arena will be at least 6 meters apart to prevent electromagnetic interference (EMI) between the units.

8. Power Interfaces

    a. NASA will provide a standard US National Electrical Manufacturers Association (NEMA) 5-15 type, 110 VAC, 60 Hz electrical jack by the network drop. This will be no more than 1.5 meters from the shelf.
    b. The team must provide any conversion devices needed to interface team access points or Mission Control Center computers or devices with the provided power sources.

9. During the setup phase, the teams will set up their access point and verify communication with their mining robot from the Mission Control Center.

10. The teams must use the USA IEEE 802.11b, 802.11g, or 802.11n standards for their wireless connection (WAP and rover client).

    a. Teams cannot use multiple channels for data transmission; meeting this rule will require a spectral mask or “maximum spectral bandwidth setting” of 20MHz for all 2.4 GHz transmission equipment.
    b. Encryption is not required, but it is highly encouraged to prevent unexpected problems with team links.
    c. During a match, one team will operate on channel 1 and the other team will operate on channel 11, See Figure 2. These channels will be monitored during the competition by NASA to assure there are no other teams transmitting on the assigned team frequency.

11. Teams must be able to use and switch between channel 1 and channel 11 for the competition within 15 minutes of being notified to accommodate real-time scheduling changes.

12. Each team will be assigned an SSID that they must use for the wireless equipment for channel 1 and channel 11.

    a. Teams SSID will be “Team_##.”

b. Teams are required to broadcast their SSID.

13. The use of specific low power (these power consumers are not part of the total power consumed COTS meter) Bluetooth transmission equipment in the 2.4 GHz range is allowed for sensors and other robot communications. Bluetooth is allowed only at power levels of Classes 2, 3, and are limited to a maximum transmit power of 2.5 mW EIRP. Class 1 Bluetooth devices are not allowed.

14. The use of 2.4 GHz ZigBee technology is prohibited because of the possibility of interference with the competition wireless transmissions.

15. Technology that uses other ISM non-licensed radio frequencies outside of the 2.4 GHz range, such as 900 MHz and 5 GHz, are allowed for robot or sensor systems, but these frequencies will not be monitored during the competition. Interference avoidance will be the responsibility of the Team and will not be grounds for protest by any team.

16. Radio Frequency Power:

    a. All Team-provided wireless equipment shall operate legally within the power requirements set by the FCC for Unlicensed Wireless equipment operating in the ISM radio band. The FCC Federal Regulations are specified in the Electronic Code of Federal Regulations, Title 47, Telecommunication, Part 15, and must be followed if any commercial equipment is modified. All unmodified commercial off the shelf access point equipment and computers already meet this requirement.
    b. If a team inserts any type of power amplification device into the wireless transmission system, this will likely create a violation of FCC rules and this is NOT allowed in the competition.
    c. This radio frequency power requirement applies to all wireless transmission devices at any ISM frequency.

17. Data Utilization Bandwidth Constraints

    a. Use of the NASA provided situational awareness camera in the control room will add 200 kb/s of data use for each camera. If the team elects to turn on the camera during the match, they will be charged for the full 200 kb/s of data use.
    b. The communications link is required to have an average data utilization bandwidth of no more than 5,000 kb/s. There will not be a peak data utilization bandwidth limit.

18. For every kg of robot mass, a typical commercial lunar lander vendor will allow 10 kbps bandwidth. Higher bandwidth will result in additional mission costs. All teams are encouraged to stay within this bandwidth allocation and the judges will assess this metric as part of the Communications bandwidth prize.

19. Radio Frequencies and Communications Approval

    a. Each team must demonstrate to the communication judges that their mining robot and access point are operating only on their assigned channel. Each team will have approximately 15 minutes at the communication judges' station.
    b. To successfully pass the communication judges' station, a team must drive their mining robot by commanding it from their mining robot driving/control laptop through their wireless access point. The judges will verify the course of travel and verify that the team is operating only on their assigned channel.

c. The teams must identify and show to the judges all the wireless emission equipment on the robot, including amplifiers and antennas. If the team has added an amplifier, written documentation shall be submitted to the judges demonstrating that the limits as designated in these rules for power transmission levels are not being exceeded.
d. If the team robot is transmitting low power Bluetooth, or is using any non-2.4 GHz frequency equipment, the following information must be provided to the judges during the communications checkout. Printed documentation from the manufacture with part numbers of all wireless transmission equipment. This printout must be from the manufacturer's data sheet or manual, and will designate the technology, frequency, and power levels in use by this type of equipment.
e. If a team cannot demonstrate the above tasks in the allotted time, the team will be disqualified from the competition.
f. The teams will be able to show the communication judges their compliance with the rules.
g. The NASA communications technical experts will be available to help teams make sure that they are ready for the communication judges' station.
h. Once the team arrives at the communication judges' station, the team can no longer receive assistance from the NASA communications technical experts.
i. If a team is on the wrong channel during their competition attempts, the team will be disqualified and required to power down.

Figure 1

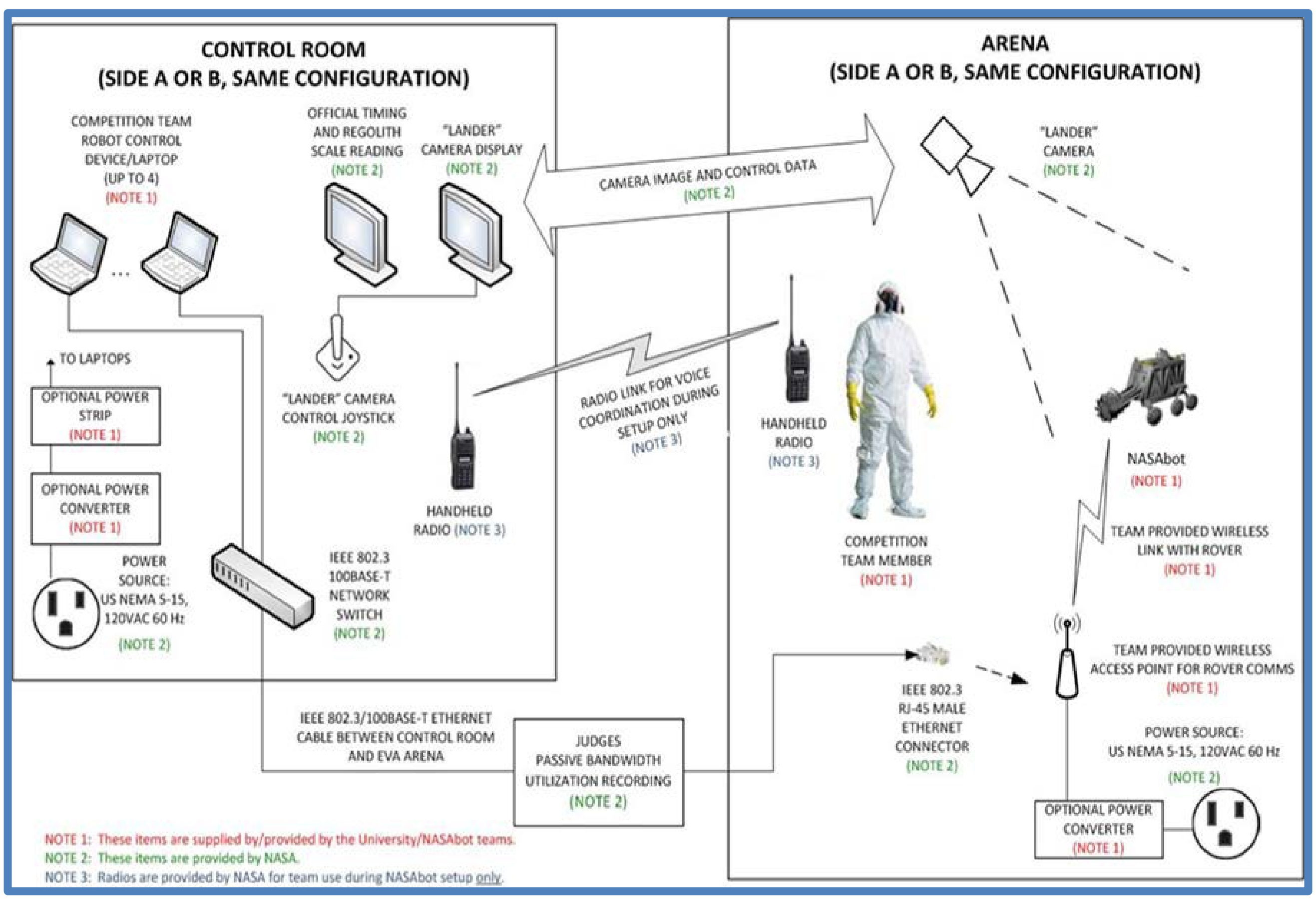
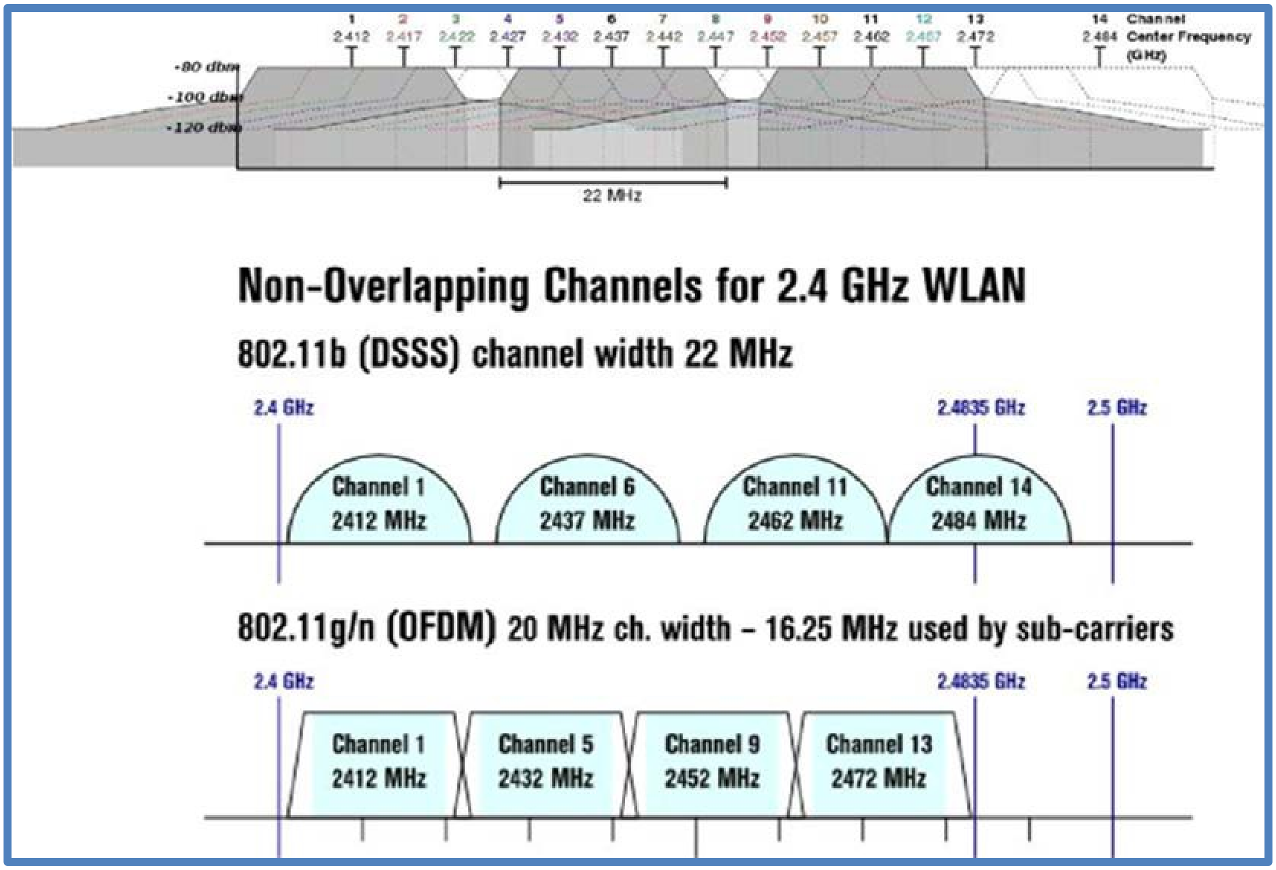


Figure 2



7.5 MINING POINTS – AUTONOMY

Autonomy: During each competition attempt, the team will earn up to 500 Mining points for autonomous operation. As Mission Control Judges (MCJ) are not intimately familiar with each robot's concept of operations (ConOps) procedures, it is the sole responsibility of the team members in the control room to coordinate with and inform the MCJ of each attempt for autonomy points in order to make sure their autonomous attempts are recognized and therefore scored correctly. Mining points will be awarded for successfully completing the following activities autonomously:

1. Excavation Automation: 50 pts

a. Teams are allowed to traverse to the Mining Arena via remote control.
b. Once in the Mining Arena they need to indicate to the MCJ that they are going hands free for the excavation attempt.
c. The robot must execute all machine control commands itself during the excavation task.
d. The robot must demonstrate the ability to dig through the upper layers of regolith and reach the icy regolith gravel. Hands free operation must begin before the robot engages the regolith to begin the excavation process. Excavation mechanisms must be completely removed from the regolith and from the excavation hole before returning to remote-control operation. Icy regolith gravel must be deposited in the robot for transport back to the hopper per the robot's design. Icy regolith gravel deposit in the

robot will be at the MCJ judgement (the intent is to show that the robot can dig down to the icy regolith and be successful in bringing up some icy regolith with completely hands free operation). MCJ may engage the arena judges for confirmation if camera angle/performance does not allow confirmation in Mission Control.

e. Once excavation is complete the team must indicate they are going to remote control before taking control.
f. This level of automation will require teams to master the lower level machine control of their robot platform associated with excavation. It is noted that past teams have proven this capability to be helpful in achieving better mining results, as the coordination of the robot for excavation can be difficult to master.

2. Dump Automation: 50 pts

a. Teams are allowed to return to the starting area via remote control.
b. The team must go into autonomous operation immediately after crossing the boundary between the obstacles and starting zones. The intent is that there is not any remote-control operation in the starting zone allowing the operator to “align” the robot to the hopper. The remote operator needs to coordinate communication with the MCJ to show hands-free operation when entering into the starting arena.
c. The robot must align, approach, stop, and dump simulated icy regolith into the hopper to be successful. The minimum of 1 kg is not required, however, at least 0.1 kg of icy regolith must be deposited. This will be as weighed by the arena judges. This level of automation will require the team to master localization near the hopper as well as path planning to align and “dock” with the hopper. Also, lower level machine control of the robot for dumping will be mastered.

3. Travel Automation: 150 pts

a. Teams may begin in remote control and move the robot within the starting zone only in order to lock in their localization solution. The teams must then indicate to the MCJ that they are going into hands free mode while still in the starting zone. The robot must remain in hands free mode while crossing the obstacle field and crossing into the mining arena. The robot must start in the starting zone and remain hands free until any part of the robot has crossed into the mining zone (as determined by the MCJ) This level of automation will require the team to master the following:

    i. Localization across the entire competition arena
    ii. Object detection and location relative to the robot
    iii. Navigational planning based on location and obstacles/traversable area
    iv. The competition will attempt to construct the obstacle field in such a way as to require obstacle detection and mapping in order to plan an appropriate route to reach the mining arena. “Point and traverse” in a straight line will not be possible due to crater and boulder obstacles.
    v. If attempting excavation automation in coordination with travel automation the robot must remain in “hands free” control during travel and excavation.

3. Full Autonomy (One cycle): 300 pts

a. The robot must be in hands free control for one entire cycle

b. Teams may begin in remote control and move the robot within the starting zone only in order to localize. Teams must begin with hands free control from the starting area and remain in hands free mode while crossing the obstacle field and crossing into the mining arena. Remaining in hands free control the robot must excavate simulated icy regolith, return to the collection bin, and successfully deposit simulated icy regolith at least one time. The minimum of 1kg is not required; however, at least 0.1 kg of icy regolith must be deposited. This will be as weighed by the arena judges.
c. This level requires mastery of all aspects of autonomy associated with this competition.

4. Full Autonomy: 500 pts

a. The robot must be in hands free control for all 15 minutes of the competition run completing two or more cycles of depositing icy regolith. The minimum requirement of 1 kg of icy regolith must be achieved to be awarded this autonomy point level.
b. This level requires mastery of all aspects of autonomy associated with this competition and demonstrates a level of robustness to complete at least two full cycles. System robustness is essential for terrestrial and extra-terrestrial mining.

5. Autonomous Operations Scoring

Sample Autonomous Operations Scoring						
	Excavation	Dump	Travel	Full – One Cycle	Full Autonomy	Total
Example 1	50	-	-	-	-	50
Example 2	-	50	-	-	-	50
Example 3	-	-	150	-	-	150
Example 4	50	50	-	-	-	100
Example 5	-	50	150	-	-	200
Example 6	50	-	150	-	-	200
Example 7	50	50	150	-	-	250
Example 8	-	-	-	300	-	300
Example 9	-	-	-	-	500	500

Any three successful completions of the Excavation, Dump, and Travel attempts will be combined for scoring. These could occur over separate passes within the 15-minute run. Points will only count for one successful completion – i.e. you can only get 50 points for excavation automation even if you use it for every pass of the run. Combining all three in one pass is the Fully Autonomous – One Cycle level.

VIII. MINING COMPETITION INFORMATION – MINING ARENA PROTOCOL

8.1 LUNAR MINING ROBOT REQUIREMENTS & SAFETY

1. The commercial cost of delivering payloads to the Moon is about $1.2 Million per kg (2019 estimate). This competition aims to simulate a Lunar mission where a robotic excavator is delivered to the Moon for regolith excavation operations. This corresponds to an approximate mission cost of $72 Million. Lower masses will result in lower mission costs so this competition rewards teams that have a lower robot mass.

2. **For RMC: Lunabotics starting in 2022** - Student teams are expected to design, construct and test their own robots, students shall do 100 percent of the work and the work must be from the current student team. Robots not constructed and/or redesigned by the entering team are NOT acceptable. A robot may be used in more than one Lunabotics Challenge; however, the reuse of the robot requires a minimum of 50 percent of the combined total structure and systems (content) to have been modified or replaced. Any team entering a robot registered previously is required to have a minimum of 50 percent new content to compete in the current year. Robots used in the Lunabotics Challenge previously without substantial change will be disqualified. Reuse of structure and systems shall be identified and explained in the SEP and Slide Presentation and Demonstration.

3. The mining robot mass is limited to a maximum of 60.0 kg. Subsystems on the mining robot used to transmit commands/data and video to the telerobotic operators are counted toward the 60.0 kg mass limit. Equipment not on the mining robot used to receive data from and send commands to the mining robot for telerobotic operations is excluded from the 60.0 kg mass limit.

4. The robot must be contained within a payload envelope of 1.0 m length x 0.5 m width x 0.5 m height. This corresponds to the typical payload volume available on today's lunar landers that are commercially available. The mining robot may deploy or expand beyond the 1.0 m x 0.5 m footprint after the start of each competition attempt, but may not exceed a 1.5 m height. During the excavated mass dumping operations only, the mining robot may deploy itself and exceed 1.5 m in height, but must be lower than the ceiling height, which is 2.5 m above the surface of the regolith.

5. Multiple mining robot(s) systems are allowed but the total mass and starting dimensions of the whole system must comply with the volumetric dimensions given in this rule.

6. KILL SWITCH - The mining robot must be equipped with an easily accessible red emergency stop button or "Kill Switch." Use good engineering practices and principles in placing the "Kill Switch" on your robot(s), failure to do so may result in a safety disqualification. The "Kill Switch" shall have a minimum diameter of 40 mm; it shall be located on the surface of the mining robot and require no additional steps to access it. Only one "Kill Switch" per robot and in the case of multiple robots, each robot will have its own "Kill Switch." It shall be easily accessible and activated in an easy and quick manner. Disabling the "Kill Switch" without authorization from the Competition Staff shall result in a safety disqualification. The emergency stop button must stop the mining robot's motion and disable power with one push motion on the button. It must be highly reliable and instantaneous. For these reasons an unmodified "Commercial Off-The-Shelf" (COTS) red button is required. A closed control signal to a mechanical relay is allowed as long as it stays open to disable the mining robot. This rule exists in order to have the capability to safe

the mining robot in the event of a fire or other mishap. The button should disconnect the batteries from all controllers (high current, forklift type button) and it should isolate the batteries from the rest of the active sub-systems as well. Only onboard laptop computers and data-logger(s) may stay powered on if powered by its own, independent, internal computer battery. For example: it is acceptable to have a small battery onboard that only powers a Raspberry Pi control computer, and whose power does not flow through the main robot kill switch.

7. The mining robot must provide its own onboard power. No facility power will be provided to the mining robot during the competition runs. There are no power limitations except that the mining robot must be self-powered and included in the maximum mining robot mass limit of 60.0 kg. The energy consumed must be recorded with a “Commercial Off-The-Shelf” (COTS) electronic data logger device. Actual energy consumed during each competition run must be shown to the judges on the data logger immediately after the competition attempt.) The ‘immediate’ part refers to the judge climbing into the arena, finding the logger and recording the power reading. If the logger is independently powered, then the robot can be remotely powered off after the run. Although this is acceptable, it is not recommended in case the robot needs to be commanded to dump collected regolith that was not deposited into the collection bin to help with cleaning the robot after the run.

8. To ensure the mining robot is usable for an actual mission, the mining robot cannot employ any fundamental physical processes, gases, fluids or consumables that would not work in an off-world environment. For example, any dust removal from a lens or sensor must employ a physical process that would be suitable for the Lunar surface. Teams may use processes that require an Earth-like environment (e.g., oxygen, water) only if the system using the processes is designed to work in a Lunar environment and if such resources used by the mining robot are included in the mass of the mining robot. Closed pneumatic mining systems are allowed if the gas is supplied by the mining robot itself. Pneumatic mining systems are permitted if the gas is supplied by the robot and self-contained.

9. Components (i.e. electronic and mechanical) are not required to be space qualified for Lunar or atmospheric, electromagnetic, and thermal environments. Since budgets are limited, the competition rules are intended to require mining robots to show an off-world plausible system functionality but the components do not have to be traceable to an off-world qualified component version. Examples of allowable components are: Sealed Lead-Acid (SLA) or Nickel Metal Hydride (NiMH) batteries; composite materials; rubber or plastic parts; actively fan cooled electronics; motors with brushes; infrared sensors, inertial measurement units, and proximity detectors and/or Hall Effect sensors, but proceed at your own risk since the BP-1 is very dusty and abrasive. Teams may use honeycomb structures as long as they are strong enough to be safe and the edges sealed to prevent dust intrusion. Teams may not use GPS, rubber pneumatic tires; air/foam filled tires; open or closed cell foam, ultrasonic proximity sensors; or hydraulics because NASA does not anticipate the use of these on an off-world mission.

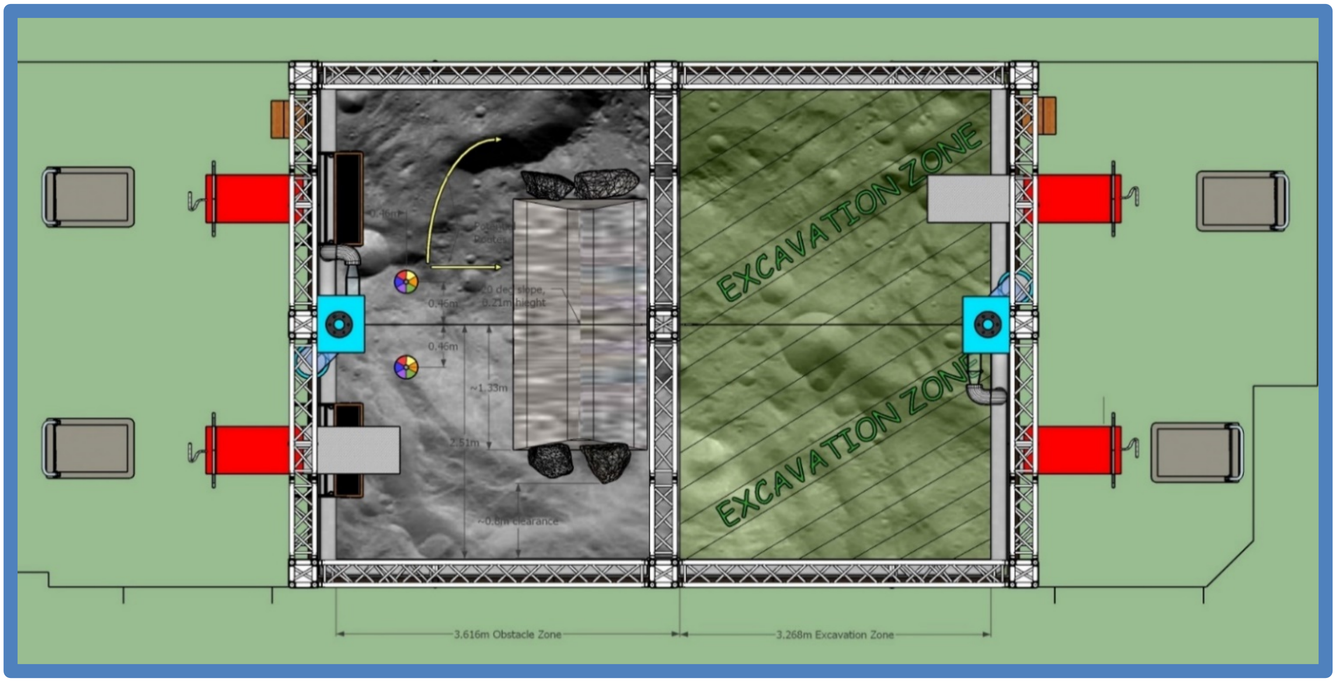
8.2 MINING ARENA INFORMATION

1. Team members shall “Suit-Up” and don their Personal Protective Equipment (PPE) to place their robot into the arena. The Arena Chief will make the final decision as to who places the robot into the arena, the number of team members allowed into the arena and any other operational process/procedure as required.

2. Teams will be required to perform two official competition attempts (15 minutes each) to mine in the arena. A minimum amount of 1.0 kg of gravel must be mined and deposited during either of the two competition attempts to qualify to win in this category. If the minimum amount of 1.0 kg is not met for an attempt, then the total score for that attempt will be zero. In the case of a tie, the teams will compete in a tie-breaking competition attempt.

3. Each mining lane is ~6.8 meters long (~3.6 meter obstacle zone plus a ~3.2 meter excavation zone) and ~2.5 meters wide.

4. The obstacle zone depth contains ~45 cm of BP-1 (regolith simulant). The mining zone depth contains ~30 cm of BP-1 over a ~15 cm bed of gravel (icy regolith simulant), with a mean particle size diameter of ~ 2 cm. Larger rocks may also be mixed in with the BP-1/gravel in a random manner. Note that the gravel may be mixed in with the BP-1, but the bulk of it will lie under the BP-1 in the mining area.



~ Regolith Mining Arena ~

5. Surface features will consist of craters on each side of the arena with randomly placed obstacles. The mining robot will be placed in the arena in a randomly selected starting position and direction. Each competition attempt will occur with two teams competing at the same time, one on each side of the arena. After each competition attempt, the boulder obstacles and craters will be returned to their starting state.

    a. There will be at least three (3) boulder obstacles placed on top of the BP-1 surface within the obstacle area before each competition attempt is made.
    b. The placement of the boulder obstacles will be randomly selected before the start of the competition.
    c. Each obstacle will have a diameter of approximately 30 cm to 50 cm and will have random heights.
    d. There will be at least two (2) craters of varying depth and width, being no wider or deeper than 40 cm.

e. No obstacles will be intentionally buried in the BP-1. BP-1 includes naturally occurring rocks.

6. No physical access to the mining robot will be allowed during each competition attempt.

7. Arena team members are prohibited from pointing out obstacles/arena surface conditions to the Mission Control Center team members. In addition, telerobotic operators are only allowed to use data and video originating from the mining robot and the NASA video monitors.

8. Visual and auditory isolation of the telerobotic operators from the mining robot in the Mission Control Center is required during each competition attempt. Telerobotic operators will be able to observe the mining arena through overhead cameras in the mining arena via monitors that will be provided by NASA in the Mission Control Center. These color monitors should be used for situational awareness only.

9. No other outside communication via cell phones, radios, other team members, etc. is allowed in the Mission Control Center once each competition attempt begins. During the 5-minute setup period, a handheld radio link will be provided between the Mission Control Center team members and team members setting up the mining robot in the mining arena to facilitate voice communications during the setup phase only.

8.3 MINING PROTOCOL

1. Teams are allowed to interact with an interface that allows different pieces of telemetry data to be viewed as long as there is no real time or other interaction to control or influence the robot. Teams must explain to the attending judge before each competition run how they are interacting with the telemetry system and the judge will observe to ensure compliance with competition rules. The robot's starting direction and location will be randomly selected immediately before the competition attempt.

2. A mining robot may only excavate BP-1 and gravel located in the respective mining zone at the opposite end of the mining arena from the starting area. Mining is allowed as soon as the mining line is crossed by the front end of the robot.

3. The mining robot is required to move across the obstacle area to the mining zone and then move back to the collection area to deposit the BP-1 and gravel into the collector sieve.

4. Each team is responsible for placement and removal of their mining robot onto the BP-1 surface. There must be one person per 20 kg of mass of the mining robot, requiring a minimum of three people to carry the maximum allowed mass of 60 kg. Assistance will be provided if needed.

5. Each team has a maximum time of 5 minutes to place the mining robot in its designated starting position within the mining arena; and 5 minutes to remove the mining robot from the mining arena after the 15-minute competition attempt has concluded and as directed by the Mining Judge.

6. The mining robot operates during the time limit of each competition attempt. The competition attempts for both teams in the mining arena will begin and end at the same time.

7. The mining robot will end operation immediately when the power-off command is sent, and

as instructed by the Mining Judge.

8. The mining robot cannot be anchored to the BP-1 and or rock/gravel surface prior to the beginning of each competition attempt.

9. The mining robot will be inspected during the practice days and right before each competition attempt. Teams will be permitted to repair or otherwise modify their mining robots while the RoboPits are open.

10. At the start of each competition attempt, the mining robot may not occupy any location outside the defined starting position in the mining arena.

11. The mining robot must operate within the mining arena; it is not permitted to pass beyond the confines of the outside wall of the arena during each competition attempt.

12. The gravel must be mined in the mining zone and deposited on the sieve frame. A team that excavates any material from the starting or obstacle areas will be disqualified for that attempt.

13. The gravel must be carried from the mining zone to the sieve frame by any means and be deposited on the sieve in its raw state. A secondary container like a bag or box may not be deposited on the sieve. Depositing a container on the sieve will result in disqualification of the team.

14. The mining robot can separate itself intentionally, if desired, but all parts of the mining robot must be under the team's control at all times. The robot does not have to re-assemble prior to the end of the competition run.

15. Any ramming of the wall may result in a safety disqualification for that attempt at the discretion of the judges.

16. The mining robot must not use the wall as support or push/scoop the gravel up against the wall to accumulate the excavated mass. If the mining robot exposes the mining arena bottom due to excavation, touching the bottom is permitted, but contact with the mining arena bottom or walls cannot be used at any time as a required support to the mining robot. Teams should be prepared for airborne dust raised by either team during each competition attempt.

17. The mining robot may not use any process that causes the physical or chemical properties of the gravel to be changed or otherwise endangers the uniformity between competition attempts.

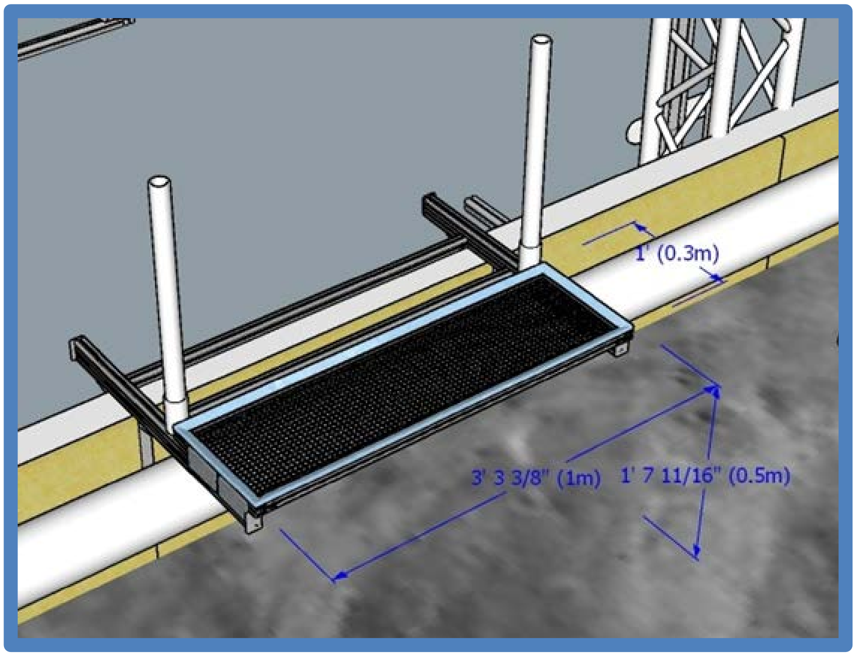
18. The mining robot may not penetrate the BP-1 surface with more force than the weight of the mining robot before the start of each competition attempt.

19. No ordnance, projectile, far-reaching mechanism, etc. may be used. The mining robot must move on the BP-1 surface.

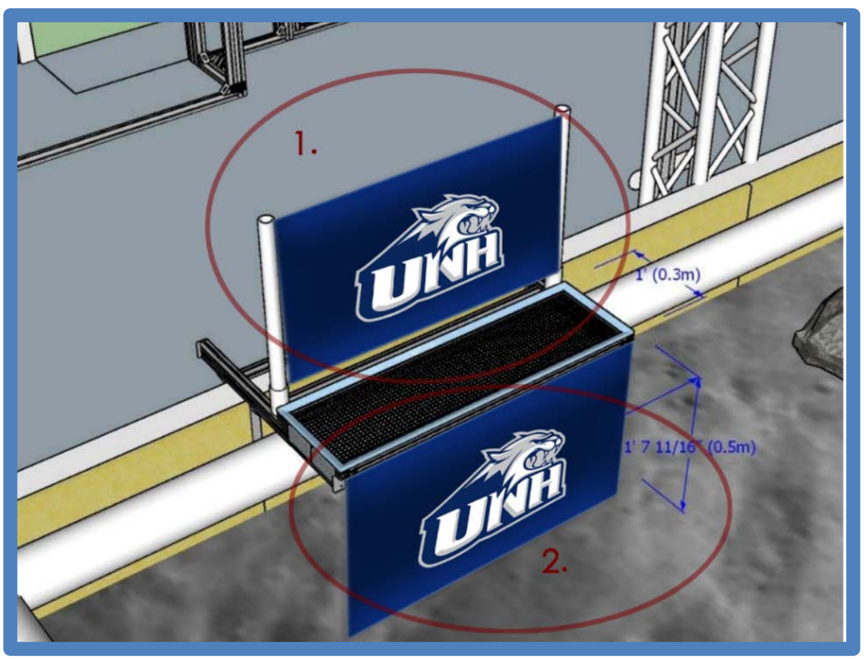
20. No team can intentionally harm another team's mining robot. This includes radio jamming, denial of service to network, gravel manipulation, ramming, flipping, pinning, conveyance of current, or other forms of attack or damage as decided upon by the judges. Immediate disqualification will result if judges deem any maneuvers by a team as being offensive in nature. Erratic behavior or loss of control of the mining robot(s) as determined by the judges

will be cause for immediate disqualification for that attempt. A judge may disable the mining robot(s) by pushing the red “Kill Switch” or emergency stop button at any time.

8.4 NAVIGATION PROTOCOL



~ Collector Sieve ~



~ Navigation Targets ~

1. The walls may not be used for the purposes of mapping autonomous navigation and collision avoidance (there are no walls on off world locations). Touching or having a switch sensor spring wire that may brush on a wall, or any other surface, as a collision avoidance sensor is not allowed.

2. Beacons or targets may be attached to the collector sieve frame for navigation purposes only. Tape, clamps or gravity may be used but screws may not be used to hold the devices in place. However, the surfaces will have a coating of the BP-1 dust that may interfere with tape adhesion. This navigational aid system must be attached during the setup time and removed afterwards during the removal time. If attached to the sieve frame, it must not exceed the length of the frame and not weigh over 4 kg. 7. Teams can attach targets to the front of the collector sieve as long as the attached target does not interfere with sliding the sieve back along the two side support rails. In other words, keep the target under 90 cm wide. These are 1.5” (ID) schedule 40 PVC tubes (vertical uprights) 29” long that are slid into smaller 2” (ID) schedule 40 PVC tubes (base sections) 5” high. The base sections are bolted to the sliding 80/20 sieve frame with 2.5” ID rigid steel pipe straps. The operational concept is for students to fasten navigation targets to the PVC vertical uprights. Students can optionally construct navigation targets ahead of time including their own 1.5” (ID) schedule 40 PVC vertical upright tubes that are ready to slide into the PVC base sections that are attached to the sieve frame. This might save operational setup time. The vertical up right centerlines are 37” apart. Standard schedule 40 PVC section dimensions are below:

ID	OD
1.5"	1.9
2"	2.375

3. The collector sieve measures 1.0 m X 0.3 m with the top of the sieve located ~0.5 m above the surface of the mining arena. All rock/gravel will be sieved out from the BP-1 at the collector sieve and weighed separately. The navigational aid system may not be higher than 0.25 m above the sieve frame, and cannot be permanently attached or cause alterations (ex: no drilling, nails, screws, etc.).

4. The mass of the navigational aid system is included in the maximum mining robot mass limit of 60.0 kg and must be self-powered.

5. The target/beacon may send a signal or light beam or use a laser based detection system which have not been modified (optics or power). Only Class I or Class II laser or low powered lasers (< 5mW) are allowed. Supporting documentation from the laser instrumentation vendor must be provided to the inspection judges for “eye-safe” lasers.

6. Inertial measurement units (IMU) are allowed on the mining robot. Teams have to explain to the judges how the compass feature will be switched off or the compass data is subtracted to ensure the internal calculations do not make use of the compass (from any magnetic field surrounding the robot).

7. Compasses (analog, digital, etc.) are not allowed on the mining robot.

8. Global Positioning Satellite (GPS) or IMU-enabled GPS devices are not allowed. Teams have to explain to the judges how the device will be switched off or the data is subtracted and ensure the internal calculations do not make use of the GPS or IMU-enabled GPS device.

9. Because of actual Lunar hardware requirements, no surface ramps leading to the collector bin of any kind will be provided or allowed.

10. The team must declare the robot orientation by length and width to the inspection judge. An arrow on the reference point (the reference location and arrow pointing forward can be any point and direction of the team's choosing, except up) must mark the forward direction of the mining robot in the starting position configuration. The judges will use this reference point and arrow to orient the mining robot in the randomly selected direction and position (you can use a permanent-type marker) indicating the team's choice of forward direction on any location on the robot is acceptable as long as multiple arrows do not conflict. The arrow does not have to indicate the robot's preferred forward direction. The arrow is used only to orientate the robot prior to starting the robot run to face the robot arrow either north, east, south or west after spinning the direction wheel).

8.5 AUTONOMOUS OPERATIONS PROTOCOL

1. For a team to earn mining points in the autonomous category, the team cannot touch the controls during the autonomous period as defined in detail below. Orientation data cannot be transmitted to the mining robot in the autonomous period.

2. Telemetry to monitor the health of the mining robot is allowed during the autonomous period.

3. The walls of the mining arena shall not be used for sensing by the robot to achieve autonomy. The team must explain to the inspection judges how their autonomous systems work and prove that the autonomy sensors do not use the walls. There are no walls on off-world locations and teams shall operate as closely as possible on that scenario of operations. Integrity is expected of all team members and their faculty advisors.

4. Failure to divulge the method of autonomy sensing shall result in disqualification from the competition.

5. During each competition attempt, the mining robot is limited to autonomous and telerobotic operations only.

6. Team operators are not permitted to update or alter the autonomy program to account / detect or upload information about obstacle locations.

7. Teams are allowed to interact with an interface that allows different pieces of telemetry data to be viewed as long as there is no real time or other interaction to control or influence the robot. Teams must explain to the attending judge before each competition run how they are interacting with the telemetry system and the judge will observe to ensure compliance with all competition rules.

IX. COMPETITION INFORMATION

9.1 SAFETY

RoboPits and Arenas

It is your responsibility to use the correct Personal Protective Equipment (PPE) for the situation. Remember to use hearing protection and eye protection (e.g., safety glasses, goggles or face shield). Proper attire consists of long-sleeved and long-torso shirts, long pants socks and closed-toe shoes. Wear gloves to de-energize robots and equipment as needed. Wear gloves when performing tasks that put you in contact with the Black Point-1 (BP-1) Lunar Basaltic Regolith Simulant such as handling dusty robots.

Use the right tool for the right job (bring jack-stands to support your robot instead of folding chairs, wire strippers should be utilized instead of knives. etc.). Without exception, the use of any respirator (N-95 masks and/or tight fitting negative pressure respirators, etc.) shall require a clean, shaven face. No facial hair shall be in contact with any part of the mask/respirator in order to maintain the seal. Remember to use good workshop, safety and engineering practices and principles. Address any safety concerns to the RoboPit Chief immediately.

Know where the fire exits, fire extinguishers and eyewash stations are located. Each team is responsible for bringing a First-Aid kit. Report any safety concerns to the RoboPits Chief. All participants are required to don Personal Protective Equipment (PPE) before coming into contact with BP-1 (the regolith simulant). If you are allergic to talcum powder, it is a good indication that you will be allergic to the Black-Point-1 (BP-1) Lunar Regolith Simulant.

The Black Point-1 (BP-1) Lunar Basaltic Regolith Simulant used in the competition is crushed lava basalt aggregate with a natural particle size distribution similar to that of lunar soil. It is alkaline and may cause skin and eye irritation.

Lunabotics Staff are authorized to issue a STOP WORK ORDER (SWO) to a team on any suspected safety issue. The team will immediately stop all activity. The Faculty Advisor and/or the Team Lead must meet with the RoboPit Chief to resolve the issue. The SWO will remain in effect until the RoboPit Chief has issued a ruling on the issue.

Respiratory

The Black Point-1 (BP-1) Lunar Basaltic Regolith Simulant used in the competition contains a small percentage of crystalline silica, which is a respiratory hazard. Respiratory protection is required for participants before coming into contact with BP-1. All participants shall use respiratory protection when required to prevent dust inhalation. Respiratory protection shall be used in accordance with the manufacturer’s operating instructions and your school’s respiratory protocols at a minimum. Without exception, the use of any respirator (N-95 masks and/or tight fitting negative pressure respirators, etc.) shall require a clean, shaven face. No facial hair shall be in contact with any part of the mask/respirator in order to maintain the seal.

Reminder

If your team uses any kind of military container, (ex. “ammo cans”) please spray-paint or cover up the former military content signage so we can avoid any work stoppages due to extra security checks.

Controlled Substances

The consumption of alcoholic beverages or use of any controlled substances by a team member during the event is prohibited. Violation is grounds for disqualification of the team.

Weapons

No weapons of any kind are permitted inside Kennedy Space Center Visitor Complex, including those belonging to off-duty law enforcement. Please leave items secured within your vehicle to expedite your entry into the visitor complex. Violation is grounds for disqualification of the team. For example, COTS wire strippers should be utilized instead of knives.

Unmanned Aerial Vehicles (UAV), Unmanned Aerial Systems

The use of Unmanned Aircraft Systems (Drones) is prohibited at the Kennedy Space Center Visitor Complex and the Astronauts Memorial Foundation Center for Space Education. The UAV/UAS will be confiscated and not returned. Violation is grounds for disqualification of the team.

Florida Weather

Stay hydrated, drink plenty of water. You and your off-world mining robots will be exposed to the Florida weather so be prepared for heat, humidity, wind and rain. You are responsible for protecting your robot from the elements while outdoors. Plan for weather when transitioning between the RoboPits (inside temperature approximately 24°C and 50% humidity) and any outside location (outside temperature averaging 32°C & 95% humidity). Remember to have hats, sunglasses, insect repellent, sunscreen (SPF 50 or better) and a raincoat / poncho on hand for the competition. Florida is the Lightning Capital of the U.S., and the lightning phase conditions are as follows:

Phase I Lightning Condition - prepare to seek shelter.
Phase II Lightning Condition - seek shelter NOW in any building.

9.2 ROBOPITS PROTOCOL

You are responsible for checking in with the RoboPits Chief upon arrival on Monday morning. The RoboPits Chief will explain the process for inspections, signing up for practice runs, and all RoboPits protocols. The RoboPits Chief is your only point of contact to coordinate practice competition runs. When things get hectic, be professional. The RoboPits Chief will require two contact phone numbers, in case the team needs to be reached at any point during the competition and cannot be found. These numbers will not be shared with anyone and will be disposed of at the end of the competition. Each team will keep their team and equipment contained within their assigned pit and keep the walkways clear and unobstructed. Hallways may be utilized for team overflow (not equipment) provided the halkway is not obstructed.

General Instructions

1. Communication (Comm) and Mechanical Inspection locations will identified.
2. The RoboPits Chief will schedule the team for the next available practice (run) slot.
3. Either inspection can be performed first, they are not scheduled, they are on a first-come, first-served basis.
4. Check with the RoboPits Chief before heading to the arena for the practice run, in case of a schedule change.
5. Return the C/I card when you have passed both the Comm and Inspection checks and are ready for a practice run.
6. Let the RoboPits Chief know if the team is going to the sandbox and will go from there to the arena for your practice run.
7. The RoboPits Chief will give the team leader the Comm/Inspection (C/I) card. The C/I card is to ensure that all teams have had their robot(s) checked out prior to entering the arena.

RoboPit Guide

1. Teams will need a placard to get through the Complex Security Gates.
2. Check robots out with the RoboPits Chief prior to leaving the Complex for the day.
3. An escort will come to the RoboPit to retrieve the team; do not leave without the escort.
4. Teams headed to the arena for competition and going to presentations have first priority on carts.
5. Following the inspection, the escort will take the team to the arena, where arena escorts will take over.
6. If the team is not ready or cannot be located, the competition run time will be given to another team that is ready.
7. All pits have power strips provided. *Do not daisy chain power strips.* Teams are encouraged to bring their own LED lighting.
8. It is recommended that the team be ready with the robot on a cart, one (1) hour prior to the scheduled competition start time, to ensure a smooth flow.
9. NASA provided carts are for shared use by all teams. Use carts to transport robots only. Carts are NOT for use in your pit. Carts are not platforms for working on the robots.
10. Vacuums are provided. They are for shared use by all teams as needed. Return vacuums to the designated area. Notify the RoboPits Chief about vacuums that need to be cleaned.
11. Presentations and Demonstrations – an escort will come to the RoboPit to retrieve the team approximately 10 minutes prior to the scheduled presentation time, do not leave without the escort.
12. The competition schedule will be sent out Tuesday afternoon to the team's point of contact. On competition days, teams will be brought to inspection 45 minutes before the scheduled competition run start time.

Clean-up and Check-out

1. Teams will check with the RoboPit Chief no earlier than Wednesday afternoon regarding any issues with shipping the robot after the competition. There will be a designated area for those robots being shipped, do not assume it can be left in your pit.
2. Each team will leave their RoboPit as they found it. Teams are required to clean their pit and

the area around it. Teams will request a RoboPit inspection from the RoboPit Chief. This process must be complete by 3 p.m. in order to attend the award ceremony Friday evening.

3. Each night the RoboPit is expected to be neat, with nothing outside of the pit boundaries. Keep the RoboPit and the surrounding area neat and generally clean; use the provided vacuums as necessary. You are encouraged to bring floor coverings/mats to facilitate this cleaning.

Waste Accumulation Protocol

Teams will comply with Federal and Kennedy Space Center hazardous and controlled waste program requirements. Regulation requires that you coordinate with the RoboPit Chief before disposing of the items listed below (specially marked containers will be provided):

Waste Accumulation and Disposal Protocol	
a. Batteries (Alkaline, Lithium, Ni-Cd)	j. Spray Paint
b. Oily wipes/IPA solvent wipes	k. Spray Foam
c. Solder waste	l. Spray Adhesives
d. Acetone wipes	m. WD40
e. PCV cement – brushes, wipes, and cans	n. PB Blaster
f. PVC primer – brushes, wipes, cans	o. Silicone Spray
g. Super Glue (cyanoacrylates)	p. Oil Cans
h. Epoxy Tubes	q. 3 in 1 oil
i. Aerosol Cans	r. any as required by regulations

For more information see:

https://www.epa.gov
https://floridadep.gov

X. COMPETITION WEEK INFORMATION

10.1 SHIPPING YOUR ROBOT

Teams may personally deliver their robot and equipment to the KSCVC on Check-In Monday or may choose to ship their robots to the event.

It is the team's responsibility to ship their containers (robots, batteries, tools, etc.) and all items in accordance with the manufacturer's specifications and comply with all state and Federal regulations. The shipping company is responsible for providing all resources required to load and unload the team's shipment/container from the shipping vehicle.

Ensure the shipping container is clearly marked with all addresses. The shipping company will go to the NASA KSC Pass & ID Office on the south side of State Road 405. Please have the shipper call 321.749.0320 two (2) hours prior to their arrival and call again on arrival. Central Receiving will send an escort to the shipper. Containers will be accepted between Monday May 10 through Friday May 14, 2021 between 9 a.m. and 2 p.m. local time.

Ship To:

NASA John F. Kennedy Space Center
ISC Central Receiving - Bldg. M6-0744
Kennedy Space Center, FL 32899,
Mark For: Lunabotics Competition, AMF Center for Space Education, Building M6-306

After the competition has ended, teams must personally remove their robots and equipment by 3:00 p.m. If teams are shipping their robots, they must clearly mark their shipping container with their address for the voyage home and notify their shipping company to pick up their container. Pickup must occur between Monday, May 24 and Wednesday, May 26, 2021 from 9 a.m. to 3 p.m. local time.

Pick-Up From:

The Astronauts Memorial Foundation (AMF)
Center for Space Education Building (CSE)
Mail Code AMF, State Road 405, Building M6-306
Kennedy Space Center, FL 32899

Do not schedule pick-ups on Saturday, Sunday or federal holidays. Shipping containers left on site will be discarded after Wednesday May 26, 2021.

10.2 CHECK-INS/CHECK-OUTS

Check-In Monday

Check-in begins Monday from at 7:30 a.m. to 3 p.m. local time. Show the parking pass to the attendant and proceed to the check-in tent in Parking Lot 4 of the Kennedy Space Center Visitor Complex (KSCVC). All your vehicles, equipment and team members shall be cleared and swept by security before being allowed into the Complex. The RoboPits and Arenas are located in the Astronauts Memorial Foundation's (AMF) Center for Space Exploration Building (CSE) (M6-306). Check-in staff will direct the teams on how to enter the park.

Check-Out Monday-Thursday, Robots and Equipment

Teams can take their robots out of the Complex at any time, however robots cannot re-enter the Complex until the next day. See Check-In, Tuesday - Friday, Robots and Equipment.

Check-In, Tuesday-Friday, Robots and Equipment

Check-in begins at 7:30 a.m. and will close at 8:30 a.m. local time. The check-in tent is located in Parking Lot 4 of the Kennedy Space Center Visitor Complex (KSCVC). All vehicles, robots, support equipment and team members shall be cleared and swept by security before being allowed into the Complex. Directions will be provided by the Check-In Staff.

10.3 COMPETITION WEEK GUIDE

Practice Days, Monday and Tuesday

Teams are encouraged to have their mining robots arrive in as complete condition as possible to take advantage of the practice runs. The spirit and intent is for each team to get at least one practice run and the opportunity to work out issues prior to the start of competition. Teams must complete robot inspection, communications check, and be cleared by the RoboPit Chief prior to signing up for a practice run. Practice runs are on a first-come first-serve basis. Practice runs may be shortened or eliminated altogether without prior notice.

Competition Days, Tuesday through Friday

The competition runs will start after the last practice runs have been completed and usually run from Tuesday through Friday and is dependent on various factors with the first run scheduled to start at 8:00 a.m. You must complete your robot inspection and communications check and be cleared by the RoboPit Chief before you can sign up for your competition run. The updated competition schedule will be sent in the evening prior to the next day's run (see below). Each team is allotted a maximum of 5 minutes to place the mining robot in its designated starting position within the Mining Arena, and 5 minutes to remove the mining robot from the Mining arena after the 15-minute competition attempt has concluded and as directed by the Mining Judge.

Opening Ceremony

The Opening Ceremony will be held on Tuesday in the Astronauts Memorial Foundations Center for Space Education Building.

Award Ceremony

The Award Ceremony will be held on Friday evening at the KSCVC's Apollo-Saturn V Complex. Buses start loading Friday evening at 5:30 pm in front of the Center for Space Education Building. Each team is allocated 12 seats for the Award Ceremony and only registered students and registered faculty are eligible to attend.

Friends and Family

The Kennedy Space Center Visitor Complex (KSCVC) opens at 9am, family or friends must have a valid KSCVC Admission Ticket for that day.

10.4 THE ROBOPITS

The RoboPits are located in the Astronauts Memorial Foundation's Center for Space Education Building M6-306. The RoboPits are equipped with emergency eyewash stations and disposal containers for used aerosol cans, batteries, degreasers and wipes used as cleaners. Teams are advised to bring additional LED lighting to the RoboPits. This is where you will be working on your robots, meeting other competitors, and after spending months designing and building, this is where you will get your robot inspected before it steps off to dig! The RoboPits are open 7:30 a.m. – 7 p.m. Monday through Thursday, and 7:30 a.m. – 3 p.m. on Friday.

10.5 TEST BED/SANDBOX

A test bed will be provided for teams to test their robots. Teams can test their robots in a silica sand environment and interact with the Visitor Complex guests. While you are here, you represent yourself, your school and NASA. Remember when things go south on your robot (and they will), there are little ears and plenty of cell phones watching you and your team.

10.6 THE BOT SHOP

The Prototype Development Laboratory's (PDL) Bot Shop is a "mobile machine shop" with grinding, sanding, mini-mill and mini-lathe, band saw, drill press and hand tools. There is no welding capability. They can help repair broken robots but do not have the capability to finish a started robot. Only NASA machinists are allowed to use the equipment. The Bot Shop is busy throughout the competition. The PDL is a team of NASA engineers and engineering technicians whose primary purpose is the design, fabrication and testing of prototypes, test articles, and test support equipment. You have the privilege of using this resource to make repairs and/or modifications to your robots.

The Bot Shop Hours

Day	Open	Close
Monday:	12 Noon	5 p.m.
Tue-Wed-Thurs:	9 a.m.	5 p.m.
Friday:	10 a.m.	12 Noon

XI. AWARDS

Design It Challenge (Phase I Only Teams) Award – 1st, 2nd, 3rd Places

Awarded to the team that scores the most points in all Phase I competition events (Plan for Project Systems Engineering, Executive Summary and Presentation).

The Efficient Use of Communications Power Award

Awarded to the team for using the lowest average data utilization bandwidth per icy regolith point earned in the official runs. Teams must collect the minimum amount of simulated icy regolith to qualify for this award.

NASA's Solar System Exploration Research Virtual Institute (SSERVI) Regolith Mechanics Award

Awarded for the best example of a granular materials-related innovation that identified a specific regolith mechanics problem (e.g. regolith flowing around the grousers, angle of repose too high in the dump bucket) and improved their design to deal with it. Presented by the NASA Solar System Exploration Research Virtual Institute (SSERVI's) Center for Lunar and Asteroid Surface Science (CLASS).

The Judges Innovation Award

Awarded to the team with best design based on creative construction, innovative technology and overall architecture.

The Caterpillar Autonomy Awards: 1st - 6th Places

The intent of the rules structure for autonomy are to incentivize competitors to pursue autonomy and develop skills in the area of on-board autonomy – perception, localization, planning, and machine control. The structure has been established to reward teams for automation of portions of the operational cycle of the competition. Automation of portions of the cycle allows teams to build capability leading to full autonomy. It should be noted that historically several teams have leveraged automation to improve their remote-control performance. Excavation automation is a great example of this approach.

Systems Engineering Leaps & Bounds Award

Awarded to the team that made a significant improvement over the previous years (or consistently sustained improvement) in their application of systems engineering to the development of their robot as demonstrated by their systems engineering paper (teams placing in the top 3 are not eligible for this award; not necessarily awarded every year).

Systems Engineering Paper Award – 1st, 2nd, 3rd Places

Papers should discuss the Systems Engineering (SE) methods used to design and build the mining robot. The purpose of the SE paper is to encourage the teams to use the SE process while designing, building and testing their robots.

Presentation and Demonstration Award – 1st, 2nd, 3rd Places

The presentation component provides the teams with the opportunity to present the spirit, intent and technical outcome of their design project. This allows the students to develop their presentation and public speaking skills, which will serve them in thesis defense and / or dissertations, grant requests, job interviews, etc.

Public Outreach Project Award – 1st, 2nd, 3rd Places

Teams must report the type of STEM outreach they have completed in their communities, the activities they provided, and the numbers they reached. Teams are encouraged to reach out to under-served / under-represented K-12 students.

Robotic Mining Award – 1st, 2nd, 3rd Places

Teams are required to design and build a mining robot that can traverse the simulated Lunar chaotic terrain. The robot must then excavate the icy regolith simulant (gravel) and return the excavated mass for deposit into the Collector Bin to simulate an off-world mining mission. The teams will have two, 15-minute competition runs to mine the icy regolith.

The Joe Kosmo Award for Excellence

Awarded to the team that scores the most points in all Phase I, Phase II and Phase III competition events. Joseph Kosmo graduated from Pennsylvania State University in 1961 with a bachelor of science in aeronautical engineering and began his career with the NASA Space Task Group in the Crew Systems Division, working on the Mercury Program spacesuit. During the past 45 years, he has participated in the design, development, and testing of Mercury, Gemini, Apollo, Skylab, and Space Shuttle spacesuits, as well as numerous advanced technology configuration spacesuits and EVA gloves for future mission applications. Kosmo received the American Astronautical Society's Victor A. Prather Award, the NASA Exceptional Service Medal, and the Astronaut Silver Snoopy Award. He has pursued the development of advanced spacesuits, gloves, and ancillary EVA-supporting hardware concepts for future planetary surface exploration. In 2011, he retired from NASA after a 50-year career in the space industry. This award honors his service and contributions to America's space program.

Award Summary

Phase I "Design It" Award

Design It Challenge (Phase I Only Teams)	$1,000

Phase II & Phase III Awards

Efficient Use of Communications Power	Trophy
SSERVI Regolith Mechanics	Trophy
Judges' Innovation	$1,000

Caterpillar Autonomy Award - 1st Place	$2,000

Caterpillar Autonomy Award - 2nd Place	$1,250
Caterpillar Autonomy Award - 3rd Place	$750
Caterpillar Autonomy Award - 4th Place	$500
Caterpillar Autonomy Award - 5th Place	$250
Caterpillar Autonomy Award - 6th Place	$250

Systems Engineering Paper - 1st Place	$3,000
Systems Engineering Paper - 2nd Place	$2,000
Systems Engineering Paper - 3rd Place	$1,000
Systems Engineering Leaps & Bounds	$250

Presentation and Demonstration - 1st Place	$3,000
Presentation and Demonstration - 2nd Place	$2,000
Presentation and Demonstration - 3rd Place	$1,000

Outreach Project Report - 1st Place	$2,000
Outreach Project Report - 2nd Place	$1,000
Outreach Project Report - 3rd Place	$750

Robotic On-Site Mining - 1st Place	$3,000
Robotic On-Site Mining - 2nd Place	$2,000
Robotic On-Site Mining - 3rd Place	$1,000

Joe Kosmo Award for Excellence	$5,000

XII. GLOSSARY OF TERMS

Accreditation Board for Engineering and Technology: The Competition rules and rubrics meets the ABET requirements for engineering and engineering technology accreditation. (http://www.abet.org)

Astronaut Memorial Foundation's Center for Space Education (CSE): Located adjacent to the Northwest end of the Kennedy Space Center Visitor Complex (KSCVC), at the Eastern terminus of Florida S.R. 405 in building M6-306.

Autonomous: The operation of a mining robot with no human interaction.

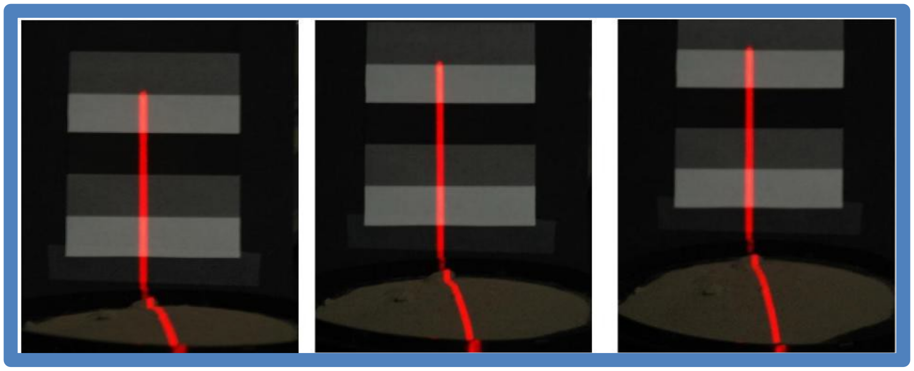
Basaltic Regolith Properties: Since the properties of regolith vary and are not well known, this competition will assume that basaltic regolith properties are similar to the Lunar regolith as stated in the "Lunar Sourcebook: A User's Guide to the Moon", edited by G. H. Heiken, D. T. Vaniman, and B. M. French, copyright 1991, Cambridge University Press (https://www.lpi.usra.edu/lunar_sourcebook/) .

Black Point-1 (BP-1): Both parameters (coefficient of friction and cohesion) are highly dependent on the humidity and compaction (bulk density, porosity) of the Lunar soil. Note the following:

- It does not behave like sand.
- The coefficient of friction has not been measured.
- There are naturally occurring rocks in the aggregate.
- BP-1 is made from crushed basalt fines and not commercially available.
- See "Soil Test Apparatus for Lunar Surfaces" http://www.nasa.gov/nasarmc
- The density of the compacted BP-1 aggregate will be between 1.5 g/cm3 and 1.8 g/cm3
- BP-1 behaves like a silty powder soil with most particles under 100 microns in diameter.
- Will be compacted and the top layer will be raked to a fluffy condition of approximately .75 g/cm3, similar to the Lunar surface.
- Teams are encouraged to develop or procure simulants based on basaltic minerals and lunar surface regolith particle size, shape, and distribution.

Black Point-1 (BP-1) Reflectivity: NASA performed tests to answer questions about BP-1 reflectivity for LIDAR (or other LASER-based) navigation systems. The laser is not a beam – it is spread out as a sheet that is oriented in the vertical direction, so it is draped across the BP-1 and across a white/gray/black target that is standing up behind the BP-1 in the images. The BP-1 is the mound at the bottom of each image. Teams can get the reflectivity of the BP-1 by comparing the brightness of the laser sheet seen reflected from the BP-1 with the brightness of the same sheet reflected from the white and black portions of the target. The three images are for the three angles of the laser. Note the BP-1 is mounded so they need to account for the fact that it is not a flat surface if they choose to analyze the brightness in the images. The three pictures below were shot with the camera at 10, 16, and 21 degrees relative to the surface. The laser was at an angle of 15 degrees. The camera speed and aperture were set to (manual mode): 1/8 s, f/4.5.

10 Degree **16 Degree** **21 Degree**



Collector Bin: A collector bin in the mining arena for each competition attempt into which each team will deposit the excavated mass. The collector bin will be large enough to accommodate each team's excavated rock/gravel and BP-1. The collector bin will be stationary and located inside the mining arena.

Competition attempt: The operation of a team's mining robot intended to meet all the requirements for winning the mining category by performing the functional task. The duration of each competition attempt is 15 minutes.

Excavated mass: Mass of the excavated rock/gravel deposited to the collector bin by the team's mining robot during each competition attempt, measured in kilograms (kg) with official result recorded to the nearest one tenth of a kilogram (0.1 kg).

Functional task: The excavation of rock/gravel from the mining arena by the mining robot and deposit of the excavated mass from the mining robot into the collector bin.

Kennedy Space Center Visitor Complex: Located at the eastern terminus of Florida S.R. 405.

Lunar regolith density: The density of regolith at the Apollo 15 landing site averages approximately
1.35 g/cm3 for the top 30 cm, and it is approximately 1.85g/cm^3 at a depth of 60 cm. The regolith also includes breccia and rock fragments from the local bedrock. About half the weight of lunar soil is less than 60 to 80 microns in size.

Mining arena: Located in the Astronaut Memorial Foundation's Center for Space Education (CSE) where the mining robot will perform each competition attempt.

Mining robot: An autonomous or tele-operated robotic excavator including mechanical and electrical equipment, batteries, gases, fluids and consumables delivered by a team to compete in the competition.

Mining points: Points earned from the two competition attempts will be averaged to determine ranking in the on-site mining category.

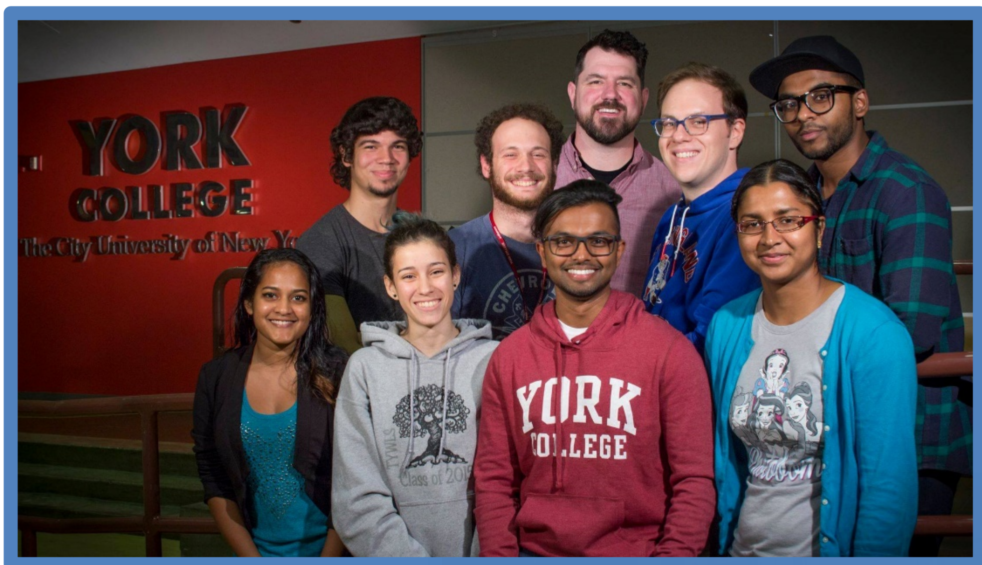
Mission Control: Operations area where teams will operate or autonomously control their robotic excavator to simulation a lunar In-Situ Resource Utilization (ISRU) mining mission. It is located outside of the arenas.

Practice time: Teams will be allowed to practice with their robots in the mining arena. NASA technical experts will offer feedback on real-time networking performance during practice attempt. The spirit and intent is for teams to get one practice run on a first come, first served basis, (however a team may get no practice runs). Practice sessions maybe shortened or eliminated due to operational issues without prior notice.

Reference point: A fixed location signified by an arrow showing the forward direction on the mining robot that will serve to verify the starting orientation of the mining robot within the mining arena.

Rock/Gravel: Intended to simulate icy-regolith buried in the South Polar region of the Moon. The gravel will be ~2 cm in diameter (minimum size) but will have random particle sizes larger than that also mixed into the gravel. The rock/gravel may be mixed in with the BP-1 in small quantities. The gravel will be made of a hard rock material, and will not have a specific color.

Telerobotic: Communication with and control of the mining robot during each competition attempt must be performed solely through the provided communications link which is required to have a total average bandwidth of no more than 5.0 megabits/second on all data and video sent to and received from the mining robot.



XIII. SUPPLEMENTAL DATA QUESTIONS

The purpose of this form is to collect data about your team's robot. Please be as thorough and accurate as possible. All responses are required using the International System of Units (SI) (ampere, kelvin, second, meter, kilogram, candela, mole). Please fill a separate form out for each of your robots at:

https://docs.google.com/forms/d/e/1FAIpQLSeB3v9iz1LoqPW2y1vLgLNlPGSW9Lt6nSRqU9jE3015Cq3C1A/viewform?usp=sf_link

1. Team Registration

1.1 School Name:
1.2 Number of Robots:
1.3 This form is for robot number ___ of ___
1.4 If more than one robot, describe specific function of this robot (ex. Mining, hauling, dumping, etc.)

2. Mobility

2.1 Does your robot have:

- ☐ Wheels
- ☐ Tracks
- ☐ Combination of both
- ☐ Other (please describe)

2.2 Wheels

2.2a Please describe anything unique or unusual about your (wheel) design.

2.2b Number of wheels

- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ 7
- ☐ 8
- ☐ 9
- ☐ 10
- ☐ Other (please describe)

2.2c Diameter of wheels (mm)

2.2d Width of tread (mm)

2.2e Spacing of wheel base, width (side to side) in mm (measure from center of wheel to center of wheel)

2.2f Spacing of wheel base length (front to back) in mm (measured from axle to axle)

2.2g Grousers?
- ☐ Yes
- ☐ No

2.2h How many grousers per wheel? (If none, answer N/A; note grousers are the short paddles on the wheel tread)

2.2i Height of grousers (mm)

2.2j Spacing between grousers (mm)

2.2k Which shape best describes your grousers
- ☐ Straight
- ☐ Diagonal
- ☐ V-shape
- ☐ Other (please describe)

2.2l What material is your tread made of?

2.2m What material are your grousers made of?

2.2n What material are your wheel hubs made of?

2.2o How many wheels are driven and which ones are they?

2.2p Are the wheels on left and right sides slaved together, or are all wheels driven independently?
- ☐ Slaved together
- ☐ Independent

2.2q Type of gearing to wheels (planetary, etc)?

2.2r How many motors on the robots are for driving (ie. If there are 4 wheels and each has its own motor, then put 4)

2.2s Motor torque for each motor (at the motor output shaft*) (in-lbs or N-m or other units – please give the units) (*If it is a combined motor/gear system purchased together as a unit, just state what you know about its torque and RPM and tell us if this is the output of the motor or at the output of the assembly after the internal gear reduction. If you know the internal gear reduction in this unit, please state it, too.)

2.2t State if this torque was rated at a particular RPM, or for locked rotor, if you know.

2.2u What is the gear reduction you used from the motor output shaft going to the wheel(s) or track(s) (ex: 40:1, or 100:1). Include all gear reduction from motor to wheel, including any gearing built-into the motor assembly multiplied by any gear reduction via external chains/sprockets, gear boxes, etc.

2.2v Does each motor have a separate motor controller channel? If some wheels are on the same motor controller channel, which ones? (Please describe)

2.3 Tracks: If your robot does not have tracks, answer each *required question with N/A and the others can be left blank.

2.3a Describe anything unusual or unique about your design if it is different than a 2 track system.

2.3b Spacing between tracks (mm)

2.3c Length of ground contact for each track (mm)

2.3d Width of tread (mm)

2.3e Tread material for tracks

2.3f Do your robot's tracks have grousers?

- ☐ Yes
- ☐ No

2.3e Tread material for tracks

2.3g Height of grousers (mm)

2.3h Spacing between grousers (mm)

2.3i Grouser material

2.3j Which shape best describes your grousers?

- ☐ Straight
- ☐ Diagonal
- ☐ V-shape
- ☐ Other (please describe)

2.3k Number of driven wheels (per track)

2.3l Number of idler wheels (per track)

2.3m How many of the idler or driven wheels are tensioners (per track)

2.3n Are the tensioners

- ☐ Wheel-driven
- ☐ Idlers

2.3o Are the tensioner wheels

- ☐ Ground-contacting
- ☐ Raised above the surface
- ☐ Other (please describe)

2.3p Are the driven wheels

- ☐ Ground-contacting

- ☐ Raised above the surface
- ☐ Other (please describe)

2.3q How many idlers are raised above the surface?

2.3r How many idlers are in ground contact?

2.3s Diameter of the driven wheels (mm)

2.3t Diameter of the idler wheels (mm)

2.3u Motor torque for the track's driven wheels

2.3v Gear ratio from motor to driven wheels

2.3w Type of gearing to driven wheels

2.4 Traction Control

2.4a Please identify and describe any implemented methods or systems designed to maintain tread or wheel traction.

3. Steering

3.1 If your robot has tracks, then tank steering (i.e., skid steering) is normal, but explain if the robot uses tracks with a unique steering method instead

3.2 If wheels, check which applies:
- ☐ Skid steering/Tank steering
- ☐ Ackerman steering
- ☐ Front wheels controlled by Ackerman steering
- ☐ Back wheels controlled by Ackerman steering
- ☐ Both sets of wheels controlled by Ackerman steering
- ☐ All wheels independently steered
- ☐ Other (Please describe)

4. Suspension

4.1 Is the robot's suspension:
- ☐ Active
- ☐ Passive
- ☐ None

4.2 Describe suspension (lead springs, rocker bogey, MacPherson strut, etc., or describe)

5. Chassis

5.1 Materials used:

5.2 Construction (tube, unibody, etc.)

5.3 Welded, bolted, riveted, etc.

5.4 Majority ground clearance in cm. (lowest part under the main area under the center of the robot to the ground)

5.5 Minimum Ground Clearance in cm (under any motors or brackets, etc, closer to the sides of the robot that stick down lower than the majority of the ground clearance)

6. Autonomy

6.1 Which autonomous operations will be attempted:
- ☐ Full autonomy
- ☐ Partial autonomy
- ☐ Tele-operated

6.2 Describe the navigation systems:

7. Regolith Mining System

7.1 Does your robot have (check all that apply)
- ☐ Auger
- ☐ Bucket ladder (eg. Buckets on chains or belt)
- ☐ Bucket drum
- ☐ Lengthwise bucket wheel
- ☐ Transverse bucket wheel
- ☐ Mining wheels
- ☐ Load/haul/dump bucket
- ☐ Scraper
- ☐ Scoop
- ☐ Rotating brush
- ☐ Other (please describe)

7.2 If other, please describe. Additionally, please describe any other strategies or unique features of your robot.

8. Regolith Transport System

8.1 Will your robot (check all that apply):
- ☐ Transport regolith in the mining device itself (in the bucket, scoop, scraper, auger, etc)
- ☐ Transfer it to a hopper for transport (including hoppers that contain conveyors)
- ☐ Place it onto a flat conveyor
- ☐ Other (please describe)

8.2 If “other” was checked please described

8.3 Estimate maximum amount of regolith that can be transported in one mining cycle (kg)

9. Regolith Unloading System

9.1 Does your robot have (check all that apply):
- ☐ Bucket ladder

- ☐ Conveyor belt
- ☐ Tilt dump from hopper, bucket, scraper, etc.
- ☐ Push out with wall or scraper
- ☐ Hatch release (gravity pulls it out)
- ☐ Reverse rotate bucket drum
- ☐ Reverse rotate auger
- ☐ Other (please describe)

9.2 If “other” was checked please describe

9.3 Does it use methods to enhance the discharge flow?

- ☐ Yes
- ☐ No

9.4 Methods used to enhance the discharge flow:

- ☐ Vibration
- ☐ Tapping
- ☐ Larger-scale jarring
- ☐ Special coatings or slippery surfaces
- ☐ None
- ☐ Other (please describe)

9.5 If special coatings or “other” was checked, please describe

10. Dust Mitigation Features

10.1 Describe any dust mitigation features designed into the robot.

11. Other Unique Features

11.1 Please describe any other unique features that may be helpful to NASA in learning how systems and materials work for space mining.

XIV. SCORE SHEETS – ROBOT INSPECTION, MINING AND MISSION CONTROL

RMC: Lunabotics / Robot Inspection & Mining / Score Sheet

School Name: ______________________ **Team No.** [ ]

Day:	M	T	W	TH	F
Practice	or	Competition			

Attempt		
1	or	2

Channel		
1	or	11

Arena		
A	or	B

ROBOT INSPECTION

Judge(s) Names: ______________________ , ______________________

Robot Mass and Volumetric Measurements

Mass: [ ] (max = 60kg) **Volume:** [ ] (max length=1m) x [ ] (max width=0.5m) x [ ] (max height=0.5m)

The mining robot may deploy or expand beyond the 1.0 m x 0.5 m footprint after the start of each competition attempt, but may not exceed a 1.5 meter height.

Dust Tolerant Design

Points 0-10 [ ] Drive train components enclosed/protected and other component selection.
Points 0-10 [ ] Custom dust sealing features (bellows, seals, etc.).
Points 0-10 [ ] Active dust control (brushing, electrostatics, etc.).

Robot Inspection Achieved [ ] NOT ACHIEVED [ ]

ROBOT MINING

Judge(s) Names: ______________________ , ______________________

Dust Free Operation

Points 0-20 [ ] Driving without dusting up crushed basalt.
Points 0-30 [ ] Digging without dusting up crushed basalt.
Points 0-20 [ ] Transferring regolith without dumping crushed basalt on your own robot.

Total Gravel (Icy-Regolith simulant) Collected [ ] (kg)

Energy Consumed

Start Value: [ ] End Value: [ ] Units: [ ]

Calculated Watt Hours: [ ]

List Rule Infractions *(can add on back of this sheet):*

1 ______________________
2 ______________________
3 ______________________

Provide Constructive Feedback to Students *(can add on back of this sheet) :*

1 ______________________
2 ______________________
3 ______________________

***** end of score sheet *****

RMC: Lunabotics / Mission Control / Score Sheet

School Name: ______________________ **Team No.** ______

Day:	M	T	W	TH	F
Practice	or	Competition			

Attempt		
1	or	2

Channel		
1	or	11

Arena		
A	or	B

MISSION CONTROL

Judge(s) Names: ______________________ , ______________________

As Mission Control Judges (MCJs) are not intimately familiar with each robot's concept of operations (ConOps) procedures, it is the sole responsibility of the team members in the control room to coordinate with and inform the MCJs of each attempt for autonomy points in order to make sure their autonomous attempts are recognized and therefore scored correctly. Mining points will be awarded for successfully completing the following activities autonomously **(see rubric for complete description of each operation)**:

Autonomous Operations

Points 0 ☐ No Operation Completed.

Points 50 ☐ Successfully Complete Excavation Automation.

Points 50 ☐ Successfully Complete Dump Automation.

Points 150 ☐ Successfully Complete Travel Automation.

Points 300 ☐ Successfully Complete Full Autonomy (One Cycle).

Points 500 ☐ Successfully Complete Full Autonomy.

Energy Consumed

Start Value: ☐ End Value: ☐ Units: ☐

Calculated Watt Hours: ☐

Camera Usage

Lander Camera Used ☐ Arena Camera Used ☐

Lander Camera **NOT** Used ☐ Arena Camera **NOT** Used ☐

List Rule Infractions *(can add on back of this sheet):*

1 ______________________

2 ______________________

3 ______________________

Provide Constructive Feedback to Students *(can add on back of this sheet)* **:**

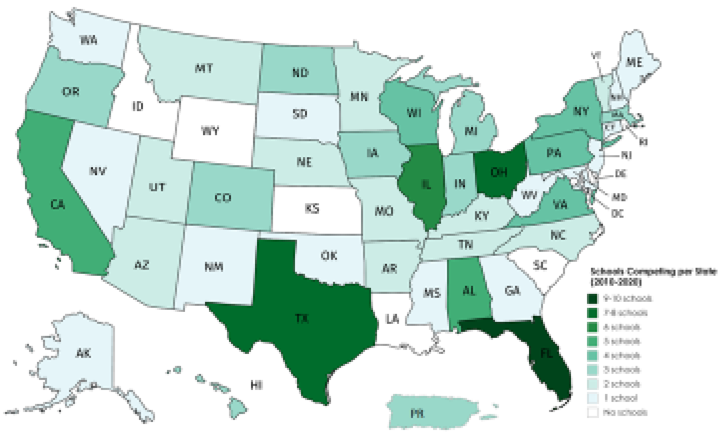
1 ______________________

2 ______________________

3 ______________________

***** end of score sheet *****

Lunabotics - history



- 43 states from Maine to Hawaii and from Alaska to the Commonwealth of Puerto Rico.
- Looking forward to the day when college teams from **Delaware, the District of Columbia, Idaho, Kansas, Louisiana, Rhode Island, South Carolina & Wyoming** will join the "Lunabotics" Artemis Challenge.

INSPIRE - ENGAGE - EDUCATE - EMPLOY
The Next Generation of Explorers

Lunabotics – NASA benefits

- From 2010 to 2019
- ***594*** proof-of-concept robots
- ***5,000*** Title I Students from Central Florida
- ***11,000*** college students
- ***1,000,000 (1M)*** -The Public Outreach effort of the 594 college teams have reported on engaging K-12 students.

INSPIRE - ENGAGE - EDUCATE - EMPLOY
The Next Generation of Explorers