COVID-19 STATEMENT

NASA has been closely monitoring developments of the COVID-19 outbreak. We are aware that many of the student teams participating in the 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. NASA is an agency of the Federal Government and will adhere to all directives issued. Thank you for your patience and understanding.

Be aware that all LUNABOTICS dates and events are subject to change and / or cancellation.

LUNABOTICS FOR 2022 AND BEYOND

There are several changes to the rules and rubrics from previous years, make no assumptions, The rules and rubrics for this year stand alone, as they do every year. It is the team’s responsibility to read and compete by this year’s rules and rubrics. During the award ceremony in May of 2021 the audience was informed that there would be a change to the challenge. This was premature and did not account the changing nature of NASA’s Artemis Mission, National and world conditions and other factors. For LUNABOTIC 2022 this will still be a Mining Challenge. To better serve and support NASA’s Artemis Program, LUNABOTICS 2023 will transition into a Lunar construction challenge. Some ideas being considered include cut and fill operations (site preparation), berm building (to protect infrastructure), placement of regolith masonry units, etc.

WHY THE MOON?

https://www.youtube.com/watch?v=bmC-FwibsZG

JOIN THE ARTEMIS MISSION TO THE MOON

https://stem.nasa.gov/artemis/
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I. INTRODUCTION

1.1 LUNABOTICS CHALLENGE

LUNABOTICS is an Artemis Student Challenge designed to educate college students in the NASA Systems Engineering process. Participating teams will use this process to design and construct a prototype robot that demonstrates the technologies required for a sustainable human presence on the Moon and other off-world locations. Competition rules evolve each year to account for NASA mission objectives and advances in commercially available technology. The competition allows NASA to gather and evaluate design and operational data for future robotic excavators and builders.

Some of the deliverables of this challenge include a Project Management Plan, Public Outreach Report, Presentation and Demonstration, a Systems Engineering Paper and more. The complexities the robots will have to master are the abrasive characteristics of the regolith simulants, the resources required to excavate and construct, the weight and size limitations of the Lunar robot and the ability to operate by remote control (tele-operate) or through autonomous operations. The commercial cost of delivering payloads to the Moon is about $1.2 Million per kg which corresponds to an approximate mission cost of $72 Million. This competition aims to simulate a Lunar mission where a robot is delivered to the Moon.

NASA directly benefits from the LUNABOTICS competition by annually assessing student designs and data the same way it does for its own, less frequent, prototypes. Encouraging innovation in student designs increases the potential of identifying clever solutions to the many challenges inherent in future Artemis missions. Advances for off-world mining and construction offer new possibilities for the same activities here on Earth, expanding the benefits beyond NASA alone. The skills developed participating in LUNABOTICS apply to other high technology industries that rely on Systems Engineering principles, helping to create a workforce posed to lead a new space-based economy and add to the economic strength of our country.

“Good for NASA, Good for America, Good for All of Us”

1.2 CODE OF CONDUCT

LUNABOTICS is a National Aeronautics and Space Administration Artemis Challenge and is 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, rubrics and all regulations. Any violation of the intent of a rule is a violation of the rule itself. Team members not adhering to the Code of Conduct will earn penalty points assessed to their teams. 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.

1.3 DISPUTES

The scoring decisions are final. If the appeal process is chosen, the faculty advisor or the team leader shall submit the appeal in writing for consideration to the Lead Judge before the last competition run of that day. The Lead Judge’s decision is final.
1.4 FREQUENTLY ASKED QUESTIONS (FAQS)

The FAQ’s serves three roles: release of new information, changes to the rules and rubrics and to respond to FAQ’s from the Faculty Advisor or Team Leads, only. The FAQ document is revised as needed, the responses to the FAQ’s become part of this Guidebook, so check the LUNABOTICS website (www.nasa.gov/offices/education/centers/kennedy/technology/nasarmc.html) frequently for any updates to the FAQ’s. It is the responsibility of the teams to read, understand and abide by all of the rules and rubrics, the FAQs, any changes contained therein and to communicate with NASA’s representatives and complete all requests for feedback.

Submit your FAQ to ksc-robotic-competition@mail.nasa.gov with the following information:
- school name
- your name & title
- your question and cite the relevant paragraph, rule, etc.
II. COMPETITION DEADLINES

All items are due by 12:00 p.m. noon, Eastern Time on the dates listed below. Teams failing to meet the deadlines will be removed from the competition. Submit all items through the website links. Do not wait until the deadline to submit.

<table>
<thead>
<tr>
<th>ITEMS</th>
<th>DUE DATE(S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Team Registration Opens at 12:00 Noon ET</td>
<td>Wed Sep 08, 2021</td>
</tr>
<tr>
<td>Team Registration Form</td>
<td>Required for Registration</td>
</tr>
<tr>
<td>Faculty Advisor Letter</td>
<td>Required for Registration</td>
</tr>
<tr>
<td>Team Registration Closes at 12:00 Noon ET</td>
<td>Wed Sep 22, 2021</td>
</tr>
</tbody>
</table>

**Phase I**

- Project Management Plan | Wed Oct 06, 2021

**Phase II**

- Faculty Registration Opens | Wed Feb 09, 2022
- Student Registration Opens | Wed Feb 09, 2022
- All Registration Closes | Wed Feb 23, 2022
- Corrections and Final Team Roster Due | Wed Mar 09, 2022
- Student Resume (optional) | Wed Mar 09, 2022
- Submit Systems Engineering Paper | Mon Apr 11, 2022
- Submit Public Outreach Project Report | Wed Apr 13, 2022
- Submit Presentation and Demonstration (optional) | Wed Apr 20, 2022
- Submit Robot Photo, Details and Proof of Life | Wed Apr 20, 2022
- Submit Team Photo with Faculty (Virtual Photo) | Wed Apr 27, 2022

**Phase III**

- ON-SITE COMPETITION WEEK | Mon May 23, 2022
- Team Check-In, 7 a.m. – 3 p.m. Eastern Time | Mon May 23, 2022
- Presentation and Demonstration Start | Tue May 24, 2022
- Practice Starts | Mon May 23, 2022
- Opening Ceremony | Tue May 24, 2022
- Competition Starts | Wed May 25, 2022
- Awards Ceremony Friday Evening | Fri May 27, 2022
III. REGISTRATION

3.1 COLLABORATIONS

Schools are encouraged to collaborate with each other and with schools classified as Minority Serving Institutions (MSI's). This is a means for teams to take advantage of the economies of scale as to costs and resources.

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. NASA will make the award to the primary school. The distribution of work, costs, awards, etc. is an arrangement between the schools. 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).

a. MSI Capability Gateway
   https://msigateway.larc.nasa.gov/

b. Minority Serving Institutions (MSI’s)
   www.doi.gov/pmb/eeo/doi-minority-serving-institutions-program

c. Eligible MSI’s
   https://www.nasa.gov/sites/default/files/atoms/files/2020-nasa-list-of-minority-serving-institutions.pdf

d. Scientific American
   https://www.scientificamerican.com/article/how-diversity-makes-us-smarter/

3.2 ELIGIBILITY

1. School / Team
   a. The school shall be an accredited post high school, vocational / technical school, college or university located in the United States, its Commonwealths, territories and or possessions.
   b. The team will be compromised of enrolled undergraduate and graduate students. The team must include at least two undergraduate students.
   c. Each team must be accompanied by an adult age 21 or older serving as the faculty advisor.
   d. The number of students on the team is at the discretion of the faculty advisor.
   e. Each team must have its own working robot(s).
2. **Students / Team members**
   a. Students shall be 18 years old at student registration. Age and enrollment verification may be requested.
   b. Students must be currently enrolled and in good standing with the school. Students who have graduated in the same semester/quarter as this challenge are eligible to be on the team.
   c. Students shall be from the same school as the team.

3. **Faculty Advisor**
   a. The faculty advisor must be currently registered and in good standing with the school.
   b. The faculty advisor shall submit a letter must include the following:
      1. A statement that the college/university is aware of and in support of the team’s participation in this design project.
      2. A statement that they have agreed to serve as the team’s Faculty Advisor for the duration of the project.
      3. A statement that the team will abide by the rules and anticipates having the resources to complete the project and attend the competition at KSC.
      4. The letter must be on the school’s letterhead.
      5. The letter must be signed by the faculty advisor.
   c. NASA reserves the right to question, accept or reject any letter if submitted by a party not authorized to represent the organization in question.

4. **Security**
   a. All team members must be cleared by NASA Security to attend this event.

3.3 **REGISTRATION**

The registration website will open at the date and time as stated. The website will close when 50 teams have completed registration or at the date and time as stated, whichever comes first. The registration website will be open only during the period listed in Section II, Competition Deadlines.

Either the Faculty Advisor or the Team Lead can register the team at:
https://secorstrategies.submittable.com/submit/1f767a20-6fd1-4032-ab0f-441e6312d517/2022-nasa-lunabotics-team-registration
IV. COMPETITION EVENTS

4.1 TWO CHALLENGES

At registration, teams must choose to compete in one of the two challenges. **Once you have chosen, you cannot change the challenge.**

- a. “Design It Challenge” (Phase I) ~ OR ~
- b. “Design It, Build It, Dig It Challenge” (Phase I, II, and III)

4.2 DESIGN IT CHALLENGE (Phase I Only)

Teams will create and submit for evaluation the design for an autonomous or tele-operated (remote controlled) Lunar robot. All deliverables are required unless otherwise stated. Submit all items through the website links, email submissions or copies are no longer acceptable. Do not wait until the deadline to submit.

**List of Deliverables:**

1. Project Management Plan
2. Design Summary
3. Presentation
4. Team Photo w/ faculty *(Virtual Photo)*

4.3 (REV 1) - DESIGN IT, BUILD IT, DIG IT CHALLENGE (PHASE I, PHASE II, PHASE III)

1. **In Phase I Design It, teams will submit:**
   The 50 highest scoring Plans will advance to Phase II. The remaining teams will be waitlisted.

2. **In Phase II Build It, teams will submit:**
   a. Systems Engineering Paper
   b. Public Outreach Project Report
   c. Presentation and Demonstration *(optional)*
   d. Student Resume *(optional)*
   e. Robot Photo with School Name – (JPEG, front, side and back of the robot).
   f. Proof of Life on YouTube link – this is a video of your robot performing two mining cycles or 5 minutes of continuous operations
   g. Your Robot Data - Provide information about your robot in Google Docs at: [https://docs.google.com/forms/d/e/1FAIpQLSeB3v9iz1LogPW2y1vLgLNIPGSW9Lt6nS RqUjiE3Q5Cq3C1A/viewform?usp=sf_linnik](https://docs.google.com/forms/d/e/1FAIpQLSeB3v9iz1LogPW2y1vLgLNIPGSW9Lt6nS RqUjiE3Q5Cq3C1A/viewform?usp=sf_linnik)
   h. Team Roster - Corrections to NASA generated Team Roster.
   i. Team Roster - Final for clearance by security. No changes after the posted date.
   j. Media Release Forms.
   k. Team Photo w/ faculty *(Virtual Photo)*

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 (at the present time...
LUNABOTICS is not authorized to have an on-site competition. In the event there are any changes, the team will be notified by email and the message will be posted on the LUNABOTICS website).

Remember all deliverables are required unless otherwise stated, teams failing to meet the deadlines will be removed from the competition. Submit all items through the website links. Email submissions or copies are no longer acceptable. Do not wait until the deadline to submit.

V. RUBRICS

5.1 PHASE I – PROJECT MANAGEMENT PLAN (REQUIRED, 10 POINTS)
Required of all “Design It, Build It, Dig It Challenge” (Phase I, II, and III) Teams

Each team shall submit a Project Management Plan electronically as a PDF.

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.

Format: The Project Management Plan shall be formatted professionally, organized clearly so that each required rubric element is easy to find, with correct spelling and grammar, with text no smaller than size 12 point font in the main body, with text no smaller than size 9 point font in graphics and tables, and using professional margins.

A video series introducing the key project management and systems engineering products and how to apply them to your project can be viewed at https://www.nasa.gov/content/systems-engineering-for-university-level-engineering-projects-and-competitions

<table>
<thead>
<tr>
<th>Scoring Rubric - Project Management Plan</th>
</tr>
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<tbody>
<tr>
<td><strong>Element</strong></td>
</tr>
<tr>
<td><strong>Initial Project Schedule</strong></td>
</tr>
</tbody>
</table>

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; for example, you hand the system over to next year’s team, dispose of it or other)

3. Major review milestones: as a minimum, these must include
   - Systems Requirements Review,
   - Preliminary Design Review,
   - Critical Design Review;
   - others may be identified as you find appropriate

4. Competition product delivery dates to the Lunabotics Engineering Competition, including as a minimum
   - delivery of Systems Engineering Paper,
   - 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 sections of your Project Management Plan. (Optionally, you may also identify any major Systems Engineering activities in your Initial Project Schedule.)

6. Discuss how you will manage the evolution of the schedule during the life of the project (how often and when you plan to review the project schedule, and how you plan to adapt to schedule slips or schedule advance opportunities).

<table>
<thead>
<tr>
<th>Initial Project Cost Budget</th>
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<tbody>
<tr>
<td>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.</td>
</tr>
</tbody>
</table>

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. Material costs, if any
   c. 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; for example, dates funds will be needed, planned activities to raise funds, or others)

| There are 3 points total for 3 elements |
3. Discuss how you will manage the evolution of the budget during the life of the project (how often you plan to review your project budget and when, and how you plan to adapt to budget shortfalls or possible cost savings should they occur).

### Design Optimization Criteria

Provide a short discussion of what your team intends to optimize (minimize or maximize) in your robot system design and operations. (For example: minimize mass, maximize automation, maximize collection of icy regolith simulant, or minimize bandwidth. You may choose other criteria.)

| 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 (for example, mass, size, bandwidth, speed, or others) 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
3. Allocation of each Technical Performance Measure across the elements of the earliest System Hierarchy (should combine to the total at the highest level)
4. Discuss any critical schedule milestones for achieving critical technical performance levels (for example, decision points in the design process where if you are unable to achieve the desired level 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 you plan to review current technical budget item values, and how you plan to adapt to performance shortfalls or exceedances should they occur).

| There are 3 total points for 5 elements |
VI. RUBRICS FOR PHASE II

6.1 SYSTEMS ENGINEERING PAPER (REQUIRED, 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.


A video series introducing the key products and techniques of systems engineering and how to apply them to your project can be viewed at https://www.nasa.gov/content/systems-engineering-for-university-level-engineering-projects-and-competitions

<table>
<thead>
<tr>
<th>Scoring Rubric - Systems Engineering Paper</th>
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<tbody>
<tr>
<td><strong>Element</strong></td>
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<tr>
<td>---</td>
</tr>
<tr>
<td><strong>Content</strong></td>
</tr>
<tr>
<td>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.</td>
</tr>
<tr>
<td>Only the first 20 pages of the main body and the first five pages of appendices will be subject to judging.</td>
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</tbody>
</table>
The cover page shall 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 the team used systems engineering in this Engineering Competition (beyond that it is required). (For example: What benefit did it provide? How was systems engineering valuable to your project? You may have other reasons.)

### Project Management Merit

1. Design Optimization Criteria:
Discuss what your team intends to optimize (minimize or maximize) in your robot system design and operations. For example: you may minimize mass; maximize automation; maximize collection of icy regolith simulant; minimize bandwidth, or any other criteria. *(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. Provide the system hierarchy for the previous robot system and identify which items were changed for this year's competition.) In the case of changes to a previous year's robot system (not an entirely new design), explain how you arrived at your decision for these changes and focus the rest of the paper on the systems engineering work you performed to develop the new/updated subsystems/components and integrate them into the whole system to perform the mission. *(two points)*

3. Major Reviews:
At a minimum, describe how you conducted the System Requirements Review (SRR), Preliminary Design Review (PDR), and Critical Design Review (CDR), and the changes that occurred to the system design, the schedule, the cost budget, and TPMs resulting from external reviewers' comments at each review. *(three points)*

8 points for 5 elements.
2 bonus points may be awarded for exceptional work on Project Management Merit elements
4. **Schedule of work:**
Discuss the project schedule and how it evolved from inception to disposal of robot system. Show the original planned schedule before project start, and as a minimum the actual final schedule, explaining what changed, why it changed, when it changed, and how the changes affected the cost budget and relevant technical requirements. When you go through a major review, it’s not unusual for the schedule to change. Demonstrate in the discussion that the schedule was used to manage the project. *(one point)*

5. **Cost budget:**
Discuss the cost budget for total project costs (including travel) and how it evolved from inception to disposal of robot system. Show the original estimated cost budget before project start, and as a minimum the actual final cost budget, explaining what changed, why it changed, when it changed, and how the changes affected the schedule and relevant technical requirements. When you go through a major review, it’s not unusual for the cost budget to change. Demonstrate in the discussion that the cost budget was used to manage the project. *(one point)*

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**Systems Engineering Merit**

1. **Concept of Operations:**
Describe how the team will operate the robot system elements, at each system hierarchy level and under the environmental conditions of the competition, to accomplish the robot system mission.

2. **System Hierarchy:**
Provide a top-down breakdown of the system design. Show that a new more detailed level in the hierarchy was the central topic reviewed and baselined at each control gate or major review (SRR, PDR, CDR).

3. **Interfaces:**
Identify the key important interfaces between elements in the system hierarchy at each system hierarchy level and their type (i.e. mechanical, electrical, human, signal, data, communication, etc.). Include key important external interfaces. Discuss how the interfaces possibly affected system design.

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 derived requirements. These are the requirements that
5. Technical Performance Measurement:
Identify and discuss technical measures that are important to achieving your Design Optimization Criteria (for example: mass, power, data — any technical characteristic that you consider important, difficult to achieve, or particularly risky to project success), how they are allocated initially to system elements in the system hierarchy, and how that allocation changes as the system design evolves through verification. Demonstrate that the budgeting and management of these important technical quantities was used in the design process.

6. Trade Studies:
Discuss how important robot system decisions were made using trade studies, i.e., using weighted evaluation criteria scorings, with key decision results captured as robot system derived requirements.

7. Reliability:
Discuss design and operations considerations for assuring successful completion of the competition and assuring safety in the event of a system component failure during operations, captured as key driving requirements.

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 section addressing Systems Engineering Merit element 4 “Requirements.” Discuss how the key important interfaces were verified.
6.2 PRESENTATION AND DEMONSTRATION (OPTIONAL, 25 POINTS)

The 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. 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>
<thead>
<tr>
<th>Scoring Rubric – Slide Presentation and Demonstration</th>
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</thead>
<tbody>
<tr>
<td><strong>Element</strong></td>
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<tr>
<td></td>
</tr>
<tr>
<td><strong>Scoring Element 1: Individual Slides</strong></td>
</tr>
<tr>
<td>1. Judging Criteria</td>
</tr>
<tr>
<td>a. Content, Formatting, and Illustrations: Each</td>
</tr>
<tr>
<td>topic is addressed in sufficient depth.</td>
</tr>
<tr>
<td>Include illustrations to support slide</td>
</tr>
<tr>
<td>content (technical content, progression of</td>
</tr>
<tr>
<td>the project, etc.). Ensure that formatting is</td>
</tr>
<tr>
<td>readable and there is a good balance of</td>
</tr>
<tr>
<td>text to graphics. Utilize proper</td>
</tr>
<tr>
<td>grammar and spelling.</td>
</tr>
<tr>
<td>b. Presenter’s Delivery: Body language,</td>
</tr>
<tr>
<td>preparedness, slide handling,</td>
</tr>
<tr>
<td>knowledgeable, passion, effective</td>
</tr>
<tr>
<td>communication.</td>
</tr>
<tr>
<td>2. Topics to Cover</td>
</tr>
<tr>
<td>a. Introduction</td>
</tr>
<tr>
<td>i. Include team name, university name,</td>
</tr>
<tr>
<td>names of team members, and faculty</td>
</tr>
<tr>
<td>advisor’s name.</td>
</tr>
<tr>
<td>b. Safety Plan</td>
</tr>
<tr>
<td>i. Robot-Specific Details: Discuss hazards</td>
</tr>
<tr>
<td>and safety features.</td>
</tr>
<tr>
<td>ii. Demonstration Safety: Discuss your plan</td>
</tr>
<tr>
<td>for the demonstration. Include hazards that</td>
</tr>
<tr>
<td>could be encountered during the</td>
</tr>
<tr>
<td>demonstration and how you have</td>
</tr>
<tr>
<td>addressed them to ensure a safe</td>
</tr>
<tr>
<td>demonstration.</td>
</tr>
<tr>
<td>c. Project and System Performance Goals</td>
</tr>
<tr>
<td>i. Qualitative</td>
</tr>
<tr>
<td>ii. Quantitative: Specify target values/</td>
</tr>
<tr>
<td>ranges</td>
</tr>
<tr>
<td>d. Project Management – Management of budget,</td>
</tr>
<tr>
<td>schedule, team, risk, etc.</td>
</tr>
<tr>
<td>e.) Design and Testing</td>
</tr>
<tr>
<td>i. General Philosophy and Process</td>
</tr>
<tr>
<td>ii. System-level Alternatives Considered</td>
</tr>
<tr>
<td>iii. Subsystem Alternative Analysis and</td>
</tr>
<tr>
<td>Development (Mining, Mechanical, Electrical,</td>
</tr>
<tr>
<td>Software and Controls)</td>
</tr>
<tr>
<td>iv. Final Configuration</td>
</tr>
<tr>
<td>v. Performance Testing (include comparison</td>
</tr>
<tr>
<td>of testing results to goals)</td>
</tr>
<tr>
<td>f.) Innovation</td>
</tr>
<tr>
<td>i. Comparison to last year and evolution</td>
</tr>
<tr>
<td>from previous years</td>
</tr>
<tr>
<td>ii. Identify efforts to evolve processes,</td>
</tr>
<tr>
<td>features, components, etc.</td>
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</tr>
</tbody>
</table>
### Scoring Element 2: Overall Package

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 (REQUIRED, 15 POINTS)

Each team must participate in an 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.

Each team must submit a report of the Outreach Project electronically in PDF by April 13, 2022 at 12:00 p.m. (noon) eastern time. 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.

<table>
<thead>
<tr>
<th>Outreach Project Report Scoring Rubric</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Elements</strong></td>
</tr>
<tr>
<td><strong>Structure, Content and Intrinsic Merit:</strong></td>
</tr>
<tr>
<td>• 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.</td>
</tr>
<tr>
<td>• Purpose for this outreach project, identify outreach recipient group(s).</td>
</tr>
<tr>
<td>• Illustrations must appropriately demonstrate the outreach project.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Educational Outreach Merit:</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>• The report must effectively describe what the outreach activity(s) was.</td>
</tr>
<tr>
<td>• 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.</td>
</tr>
<tr>
<td>• The report must reflect how the outreach project inspired others to learn about robotics and engineering. The outreach must be STEM focused.</td>
</tr>
<tr>
<td>• 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.</td>
</tr>
<tr>
<td>• The report must reflect how the team inspired 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.</td>
</tr>
<tr>
<td>• 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.</td>
</tr>
<tr>
<td>• Activities must relate in some way to the Lunabotics Competition.</td>
</tr>
<tr>
<td>• 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 encourage the students to pursue STEM? Are you providing teachers the tools they need to</td>
</tr>
</tbody>
</table>

21
reinforce your projects?

- The report must show statistics on the participants. How many children did you reach? What age range/grade-level? For your virtual outreach, 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:

- The report must clearly describe activities, processes, and milestones used to engage underserved and underrepresented populations.
- 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.
- 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 MINING (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. The goal is to give each team two practice attempts. 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. Each practice attempt and each competition attempt will consist of 5 minutes set up, 15 minutes run time and 5 minutes to safe and remove the robot from the arena.

7.2 SCORING

<table>
<thead>
<tr>
<th>Mining Category Elements</th>
<th>Units</th>
<th>Specific Points</th>
<th>Example Actuals</th>
<th>Example Mining Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. <strong>Pass All Inspections (Comm/Vehicle).</strong></td>
<td>1,000=Pass / 0=Fail</td>
<td>0 or 1,000</td>
<td>1,000.00</td>
<td>1000.00</td>
</tr>
<tr>
<td>2. <strong>Gravel Mined</strong> - 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).</td>
<td>kg</td>
<td>10.00</td>
<td>11.00</td>
<td><strong>100.00</strong></td>
</tr>
<tr>
<td>3. <strong>Average Data Bandwidth Use</strong> - 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).</td>
<td>Kbps/sec</td>
<td>-0.02</td>
<td>1066.00</td>
<td><strong>-21.32</strong></td>
</tr>
<tr>
<td>4. <strong>Camera Bandwidth Use</strong> - During each competition attempt, the team will lose 200 pts for each situational awareness camera used (camera and width usage 200 kbps/camera).</td>
<td>Kbps/camera</td>
<td>-200.00</td>
<td>400.00</td>
<td><strong>-8.00</strong></td>
</tr>
<tr>
<td>5. <strong>Mining Robot Mass</strong> - 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).</td>
<td>kg</td>
<td>-8.00</td>
<td>60.00</td>
<td><strong>-480.00</strong></td>
</tr>
</tbody>
</table>
6. **Report Energy Consumed** - 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 data logger and verified by a judge (-1/watt-hour).

| watt-hour | -1.00 | 9.00 | -9.00 |

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, 100, 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 manufacturer 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.
Non-Overlapping Channels for 2.4 GHz WLAN

802.11b (DSSS) channel width 22 MHz

802.11g/n (OFDM) 20 MHz ch. width – 16.25 MHz used by sub-carriers
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.

4. 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.

5. 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.
6. Autonomous Operations Scoring

<table>
<thead>
<tr>
<th></th>
<th>Excavation</th>
<th>Dump</th>
<th>Travel</th>
<th>Full – One Cycle</th>
<th>Full Autonomy</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ex: 1</td>
<td>50</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>50</td>
</tr>
<tr>
<td>Ex: 2</td>
<td>-</td>
<td>50</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>50</td>
</tr>
<tr>
<td>Ex: 3</td>
<td>-</td>
<td>-</td>
<td>150</td>
<td>-</td>
<td>-</td>
<td>150</td>
</tr>
<tr>
<td>Ex: 4</td>
<td>50</td>
<td>50</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>100</td>
</tr>
<tr>
<td>Ex: 5</td>
<td>-</td>
<td>50</td>
<td>150</td>
<td>-</td>
<td>-</td>
<td>200</td>
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<tr>
<td>Ex: 6</td>
<td>50</td>
<td>-</td>
<td>150</td>
<td>-</td>
<td>-</td>
<td>200</td>
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<tr>
<td>Ex: 7</td>
<td>50</td>
<td>50</td>
<td>150</td>
<td>-</td>
<td>-</td>
<td>250</td>
</tr>
<tr>
<td>Ex: 8</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>300</td>
<td>-</td>
<td>300</td>
</tr>
<tr>
<td>Ex: 9</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>500</td>
<td>500</td>
</tr>
</tbody>
</table>

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. REQUIREMENTS

8.1 ROBOT REQUIREMENTS

1. The Lunar robot:
   a. shall have maximum undeployed volume = 1.1 m length x 0.6 m width x 0.6 m height
   b. will have a maximum mass of 80kg.
   c. the robot can run either by telerobotic (remote control) or autonomous operation.
   d. subsystems used to transmit commands / data and video to the telerobotic operators are counted toward the mass limit. Equipment not on the robot used to receive data from and send commands to the robot for telerobotic operations is excluded from the mass limit.
   e. may deploy or expand beyond the envelop after the start of each competition attempt but may not exceed a 1.5 m in height.
   f. multiple robot systems are allowed, but the total mass and starting dimensions of the whole system must comply with the volumetric dimensions given in this rule.

2. The “KILL SWITCH” - The 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 construction 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 construction 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 robot. This rule exists in order to have the capability to save the construction 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.

3. The robot must provide its own onboard power. No facility power will be provided to the robot during the competition runs. There are no power limitations except that the robot must be self-powered and included in the maximum mass limit. 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 complete an operation so that it can be removed from the arena.

4. To ensure the robot is usable for an actual mission, it 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 robot are included in the mass of the robot. Closed pneumatic systems are allowed if the gas is supplied by the robot itself. Pneumatic systems are permitted if the gas is supplied by the robot and self-contained.

5. 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 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 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

1. The Artemis Arena:
   a. Measures ~ 6.8m x ~ 5.0m
   b. Each mining lane is ~6.8m long and ~2.5m wide.
   c. The excavation zone measures ~2.5m long.

2. The Mining Zone:
   a. Contains ~30 cm of BP-1 over a ~15 cm bed of gravel (icy regolith simulant).
   b. Larger rocks may also be mixed in with the BP-1/gravel in a random manner (gravel is ~2cm in diameter).
   c. The target sieve is 1.0 meter wide by 0.31 meter deep. The top lip of the sieve as shown in the attached image will be exactly 0.5 meter off the surface of the regolith.

3. 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.

4. Teams will be required to perform two official competition attempts (15 minutes each) to mine in the arena:
   a. 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.
   b. If the minimum amount of 1.0 kg is not met for an attempt, then the total score for that attempt will be zero.
   c. In the case of a tie, the teams will compete in a tie-breaking competition attempt.
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.

6. 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 50 cm.
   e. No obstacles will be intentionally buried in the BP-1. BP-1 includes naturally occurring rocks.

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

8. 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.

9. 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.

10. 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 ROBOT 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. 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

1. The walls may not be used for the purposes of mapping autonomous navigation and collision avoidance, compasses (analog, digital, etc.) are not allowed on the robot (there are no walls or mapped magnetic fields 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 also, not allowed.

2. 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.).

3. 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.

4. 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.

5. The mass of the navigational aid system is included in the maximum mining robot mass limit of and must be self-powered.
6. 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.

7. 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).

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**

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

a. *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.

b. 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.

c. 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.

d. 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 lunar soil. It is alkaline and may cause skin and eye irritation.

e. All 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.

f. *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.
g. **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.

h. **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.

i. **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.

j. **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.

k. **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 ROBOPIT 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 hallway is not obstructed.
General Instructions

1. Communication (Comm) and Mechanical Inspection locations will be 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.
4. 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):

<table>
<thead>
<tr>
<th>Waste Accumulation and Disposal Protocol</th>
</tr>
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<tbody>
<tr>
<td>a. Batteries (Alkaline, Lithium, Ni-Cd)</td>
</tr>
<tr>
<td>b. Oily wipes/IPA solvent wipes</td>
</tr>
<tr>
<td>c. Solder waste</td>
</tr>
<tr>
<td>d. Acetone wipes</td>
</tr>
<tr>
<td>e. PCV cement – brushes, wipes, and cans</td>
</tr>
<tr>
<td>f. PVC primer – brushes, wipes, cans</td>
</tr>
<tr>
<td>g. Super Glue (cyanoacrylates)</td>
</tr>
<tr>
<td>h. Epoxy Tubes</td>
</tr>
<tr>
<td>i. Aerosol Cans</td>
</tr>
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For more information see:

https://www.epa.gov
https://floridadep.gov
X. COMPETITION WEEK INFORMATION

10.1 HOURS OF OPERATION

<table>
<thead>
<tr>
<th>Check-In</th>
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<tbody>
<tr>
<td>Day</td>
<td>Open</td>
<td>Close</td>
</tr>
<tr>
<td>Monday</td>
<td>7 a.m.</td>
<td>3 p.m.</td>
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<th>Check-In</th>
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<tr>
<td>Day</td>
<td>Open</td>
<td>Close</td>
</tr>
<tr>
<td>Tuesday-Friday</td>
<td>7 a.m.</td>
<td>8 a.m.</td>
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<table>
<thead>
<tr>
<th>The Bot Shop</th>
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<tbody>
<tr>
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</tr>
<tr>
<td>Monday</td>
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<td>5 p.m.</td>
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<tr>
<td>Tue-Wed-Thurs</td>
<td>9 a.m.</td>
<td>5 p.m.</td>
</tr>
<tr>
<td>Friday</td>
<td>9 a.m.</td>
<td>12 Noon</td>
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<thead>
<tr>
<th>The RoboPits</th>
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<tbody>
<tr>
<td>Day</td>
<td>Open</td>
<td>Close</td>
</tr>
<tr>
<td>Monday-Thurs</td>
<td>7 a.m.</td>
<td>7 p.m.</td>
</tr>
<tr>
<td>Friday</td>
<td>7 a.m.</td>
<td>3 p.m.</td>
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<table>
<thead>
<tr>
<th>Award Ceremony</th>
<th>Start</th>
<th>End</th>
</tr>
</thead>
<tbody>
<tr>
<td>Friday Bus Loading</td>
<td>5:15 p.m.</td>
<td>~</td>
</tr>
<tr>
<td>Ceremony</td>
<td>6:30 p.m.</td>
<td>9:00 p.m.</td>
</tr>
</tbody>
</table>

10.2 ON-SITE WEEK

a. **Security – Without Exception**, all vehicles, robots, support equipment and team members shall be cleared and swept by security before being allowed to proceed. There will be random security patrols and your team may be asked to clear your RoboPit for additional security measures. Please comply with all requests from NASA Security. Remember the Kennedy Space Center is an operational range with safety and security having priority. Please be patient during any delays.

b. **Check-In Monday (7:00 a.m. – 2:00 p.m.)** - Check-in begins Monday. 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 to proceed. 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.
c. **Check-Out Monday-Thursday, Robots and Equipment** - Robots can check-out of the RoboPits at any time. However, you cannot re-enter the Complex until the next day. See Check-In, Tuesday - Friday, Robots and Equipment.

D. **Check-In, Tuesday-Friday, Robots and Equipment (~7:30 a.m. - ~8:30 a.m.)** - 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 to proceed. Directions will be provided by the Check-In Staff. Remember the Kennedy Space Center is an operational range with safety and security having priority. Please be patient during any delays.

e. **Practice Days, Monday and Tuesday** - Teams are encouraged to have their construction 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.

f. **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. 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.

h. **Award Ceremony** - The Award Ceremony will be held Friday evening at either the Atlantis Center or at the Apollo-Saturn V Complex (ASV). For the ASV, buses start loading Friday evening at ~ 5:00 pm in front of the Center for Space Education Building (M6-306). Each team is allocated 10 seats for the Award Ceremony and only registered students and registered faculty are eligible to attend.

i. **Friends and Family** - The Kennedy Space Center Visitor Complex (KSCVC) opens at 9am. Family and friends must have a valid KSCVC Admission Ticket to see the competition ([https://www.kennedyspacecenter.com/](https://www.kennedyspacecenter.com/)).

### 10.3 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, power strips and first-aid kits 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 goes to work.
10.4 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.

10.5 SHIPPING YOUR ROBOT

Teams may bring or ship their robots to the competition. It is the team’s responsibility to use a reputable shipping agency as well as to ship it in time to make it to the competition.

a. Shipping to the Competition

The shipping company is responsible for providing all resources required to load and unload the container from the shipping vehicle.

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 Monday through Thursday 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

b. Shipping Back Home

The shipping company is responsible for providing all resources required to load and unload the container from the shipping vehicle.

Schedule your pick-up Monday through Thursday between 9 a.m. to 3 p.m. local time. Do not schedule pick-ups on Saturday, Sunday or on federal holidays. Shipping containers left on site will be discarded on Friday morning after the end of the on-site competition week.

**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
XI. AWARDS

11.1 WINNING SCORES

a. The winner of the Joe Kosmo Award for Excellence is calculated as follows:
   + Project Management Plan (10 Points)
   + Systems Engineering Paper (25 Points)
   + Presentation and Demonstration (Optional) (25 Points)
   + Public Outreach Report (15 Points)
   + Mining (25 Points)
   ________________________________
   = Joe Kosmo Award for Excellence Winner

11.2 AWARDS

a. 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 also collect the minimum amount of simulated icy regolith to qualify for this award.

b. The Judges Innovation Award
   Awarded to the team with best design based on creative construction, innovative technology and overall architecture.

c. 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.

d. 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).

e. 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.

f. 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.

g. **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.

h. **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.

i. **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.
### j. Award Summary

<table>
<thead>
<tr>
<th>COMPETITION AWARDS</th>
<th>Points</th>
<th>Scholarship</th>
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</thead>
<tbody>
<tr>
<td>Project Management Plan</td>
<td>Up to 10</td>
<td>$ 500.00</td>
</tr>
<tr>
<td>Efficient Use of Communications Power</td>
<td></td>
<td>$ 500.00</td>
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<tr>
<td>Judges’ Innovation</td>
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<td>$ 500.00</td>
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<tr>
<td>Caterpillar Autonomy Award - 1st Place</td>
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<td>$ 2,000.00</td>
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<tr>
<td>Caterpillar Autonomy Award - 2nd Place</td>
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<td>Caterpillar Autonomy Award - 3rd Place</td>
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<td>Caterpillar Autonomy Award - 4th Place</td>
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<td>Caterpillar Autonomy Award - 5th Place</td>
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<tr>
<td>Caterpillar Autonomy Award - 6th Place</td>
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<td>$ 250.00</td>
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<tr>
<td>Systems Engineering Paper - 1st Place</td>
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<tr>
<td>Systems Engineering Paper - 2nd Place</td>
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<tr>
<td>Systems Engineering Paper - 3rd Place</td>
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<tr>
<td>Systems Engineering Leaps &amp; Bounds</td>
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<td>$ 250.00</td>
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<td>Presentation and Demonstration - 1st Place</td>
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<tr>
<td>Outreach Project Report - 1st Place</td>
<td>Up to 15</td>
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<td>Outreach Project Report - 3rd Place</td>
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<tr>
<td>Robotic On-Site Mining - 1st Place</td>
<td>Up to 25</td>
<td>$ 3,000.00</td>
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<tr>
<td>Robotic On-Site Mining - 2nd Place</td>
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<tr>
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<td>$ 5,000.00</td>
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XII. GLOSSARY OF TERMS

Accreditation Board for Engineering and Technology: The Competition rules and rubrics are aligned 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.


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:

1. It does not behave like sand.
2. The coefficient of friction has not been measured.
3. There are naturally occurring rocks in the aggregate.
4. BP-1 is made from crushed basalt fines and not commercially available.
5. See “Soil Test Apparatus for Lunar Surfaces” http://www.nasa.gov/nasarmc
6. The density of the compacted BP-1 aggregate will be between 1.5 g/cm3 and 1.8 g/cm3
7. BP-1 behaves like a silty powder soil with most particles under 100 microns in diameter.
8. Will be compacted and the top layer will be raked to a fluffy condition of approximately .75 g/cm3, similar to the Lunar surface.
9. 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.
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/cm³ 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 simulate 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
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

2.3g 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.
This is the Astronauts Memorial Foundations Center for Space Education Building (M6-306). This is the LUNABOTICS venue for all events.