LUNABOTICS 2025

NASA LUNABOTICS 2025

GUIDEBOOK

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TABLE OF CONTENTS

SECTION 1: APPLICATION AND ADMINISTRATION

1.	Lunabotics Objectives	1
2.	Lunabotics Events	1
3.	Lunabotics Regulations and Policies	1
4.	Mission First	2
5.	Roles and Responsibilities	2
6.	Code of Conduct	2
7.	Appeals	2
8.	Participant Waiver	2
9.	Social Media	2
10.	Media Advisory	2
11.	Mentor/Protégé Teams	2
12.	Why the Moon	3
13.	The Lunabotics Awards	3
14.	Eligibility	4
15.	Alignment with National Standards in Engineering and Space	4
16.	Minority Serving Institutions	5
17.	Applying to Lunabotics	5

SECTION 2: TECHNICAL

1.	RoboPits	10
2.	Check-in and Set-up	10
3.	Team Spirit	10
4.	Safety and Communication Inspection	10
5.	Preparing for Competition Attempt	10
6.	Clean-up and Check-out	10
7.	Stop Work Order (SWO)	10
8.	Prototype Development Laboratory’s Bot Shop	11
9.	Waste Accumulation Protocol	11
10.	Safety in the RoboPits and Artemis Arena	11

11. Personal Protective Equipment (PPE) 11
12. Regolith Simulant – Black Point-1 (BP-1) 11
13. Respirators 11
14. Eye/Face Protection 12
15. Hand Protection 12
16. Hearing Protection 12
17. Foot Protection 12
18. Clothing Allowed 12
19. Clothing Not Allowed 12
20. Spectators 13
21. Personal Protective Equipment (PPE) 13
22. Donning Protocol 13
23. Doffing Protocol in the Artemis Arena 13

Artemis Arena Specifications and Protocol

1. Artemis Arena Specifications 14
2. Artemis Arena Protocol 15

Robots and Robotic Operations

1. Robots 17
2. Robot Requirements 17
3. E-STOP Button 17
4. Power Meters/Data Loggers 18
5. Battery Protocol 18
6. Robotic Operations 19

Scoring, Construction, Navigation

1. Scoring 20
2. Construction Points 20
3. Construction Points Calculator 22
4. Construction Protocol 23
5. Navigation Protocol 24
6. Autonomy Rules 24

Mission Control Center and Autonomous Operations

1. Mission Control Center (MCC) 25
2. Autonomous Operations 27
3. Selected Teams 30

SECTION 3: DELIVERABLES AND RUBRICS

1. Project Management Plan (PMP) 31
2. STEM Engagement Support Rubric 35
3. Presentation and Demonstration (P&D) Rubric 39
4. Systems Engineering Paper Rubric 41
5. Proof of Life (PoL) Video & Robot Data 46

Waste Management Overview 48

Media Release 51

Waiver of Liability 52

SECTION 4: LUNABOTICS WEEK AT THE KENNEDY SPACE CENTER (KSC)

Project Partners 54

Construction – Two On-Site Events 55

First Responders 56

Miscellaneous 57

Daily Schedule 58

On-Site Week 59

Additional Activities 61

Glossary of Terms 62

Google Scholar 64

SECTION 1: APPLICATION AND ADMINISTRATION

1. Lunabotics Objective

The primary objective of Lunabotics is for teams of college students to apply the NASA systems engineering process to design, develop, build, and test a prototype lunar robot. The goal is to construct berm structures that would be useful for blast and ejecta protection during lunar landings and launches, shading lunar housing, cryogenic propellant tank farms, providing radiation protection around a nuclear power plant, and other mission-critical uses.

Lunabotics is a two-semester event that allows selected teams to earn points by successfully completing the STEM Engagement Report, the Presentation and Demonstration (optional), the Systems Engineering Paper, the Proof of Life Video, and developing robots that meet all the challenge criteria.

NASA directly benefits from this 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 the Artemis missions. Advances for off-world construction offer new possibilities for the same activities here on Earth, expanding the benefits beyond NASA alone. The skills developed in Lunabotics apply to other high-technology industries that rely on systems engineering principles. These industries will create a workforce posed to lead a new space-based economy and add to the economic strength of our country.

2. Lunabotics Events

This is the gateway to the overall challenge. Applicants will follow the directions listed in “Applying on the STEM Gateway Website.” You will receive an email letting you know the selection status of your application. Those teams selected will continue with the challenge consisting of the following events:

Event 1 – Project Development Challenge:

1. STEM Engagement Report
2. Presentation and Demonstration Slides
3. Systems Engineering Paper
4. Proof of Life Video

Teams failing to submit any of these items will be removed from the challenge.

Event 2 – University of Central Florida Lunabotics Qualification Challenge

1. This event is held at UCF’s Florida Space Institute’s Exolith Lab® in Orlando, Florida.
2. Here, the teams will put their designs to the test. The 10 highest-scoring teams from UCF’s Qualification Challenge will be invited to NASA’s On-Site Challenge at the Kennedy Space Center. Teams that do not reach the top 10 will also be invited to this event, but they will not be given the opportunity to run their robots.

Event 3 – NASA’s Lunabotics On-Site Challenge

The 10 highest-scoring teams from the UCF Lunabotics Qualification Challenge will be invited to the Kennedy Space Center (KSC) to compete in the Artemis Arena located in the Astronauts Memorial Foundation’s Center for Space Education Building.

3. Lunabotics Regulations and Policies

First, read the Lunabotics Guidebook at (https://www.nasa.gov/learning-resources/lunabotics-challenge/).

Frequently Asked Questions / Ask for Help

1. There will be no response to requests for information already contained in the Guidebook, to change a deadline or a rubric.
2. The team is responsible for monitoring the Lunabotics Website and the Lunabotics Facebook page for notices, updates, feedback requests, and responses to FAQs. The Guidebook and the FAQs shall be read together as one document.
3. The faculty advisor and/or team leads shall submit the FAQs. Email shall use an “.edu” domain address. This applies to the application process and communications with Lunabotics. We can only respond to “.edu” addresses.

4. Provide your school's name, cite the relevant rule/paragraph number in the guidebook, your inquiry, and send it to KSC-Lunabotics@mail.nasa.gov. There will be no response to inquiries from any other source.
5. We understand the on-site events may conflict with final exams and /or your commencement ceremony. We can assist with proctoring exams on-site; please don't ask us to change dates or deadlines.

4. Mission First

Be advised the Kennedy Space Center is an active launch range. NASA mission requirements may change deadlines and deliverables and/or cancel the event itself without prior notice.

5. Roles and Responsibilities

It is the responsibility of the NASA Chief Judge and Project Manager to ensure the integrity of the challenge as to the interpretation and enforcement of the rules and rubrics in the Guidebook. The goal is to apply the content of the Guidebook equally to the participants without passion or prejudice. The Lead Judges are responsible for creating the rules and rubrics and judging the deliverables received from the teams for their events. In matters associated with the overall Lunabotics Challenge, the Chief Judge and Project Manager's decision shall prevail.

6. Code of Conduct

Lunabotics is a National Aeronautics and Space Administration (NASA) Artemis Student Challenge and is held in a positive and safe environment. Students and faculty shall conduct themselves with integrity as to the spirit and intent of the rules, rubrics, and regulations. Violation of the intent of a rule is a violation of the rule itself. A team found in violation of the rules and rubrics, exhibiting unprofessional behavior, or not following the directions of the Lunabotics staff may be assessed penalty points or may be disqualified from a competition run or the entire Challenge. The Lunabotics Staff have the authority to act in this manner.

7. Appeals

All scoring decisions are final. If an appeal is warranted, the advisor or the student team leader shall submit the appeal in writing for consideration to the Chief Judge / Project Manager within 30 minutes of the posting of score(s) in question. The final decision of the Chief Judge / Project Manager shall prevail.

8. Participant Waiver

Participants hereby waive any claims against NASA, its employees, its related entities (including, but not limited to, contractors and subcontractors at any tier, grantees, investigators, volunteers, customers, users, and their contractors and subcontractors at any tier), and employees of NASA's related entities for any injury, death, or property damage/loss arising from or related to NASA's Lunabotics, whether such injury, death, or property damage/loss arises through negligence or otherwise, except in the case of willful misconduct.

9. Social Media

The Lunabotics Facebook page allows us to post notifications to the teams and the teams to communicate with each other, post photos, etc. Remember to "Like Us".

10. Media Advisory

All participants and visitors to Lunabotics at the Kennedy Space Center or to the Lunabotics Qualification Challenge at the University of Central Florida (UCF) Center for Lunar and Asteroid Surface Science (CLASS) give permission to be photographed /videotaped by NASA or its representatives for potential use in future media products, unconditionally releasing NASA and its representatives from any claims and demands.

11. Mentor/Protégé Teams

1. NASA collaborates with space agencies around the globe on many programs, including the International Space Station, Earth observation, and the Artemis missions headed to the Moon and Mars. Building and nurturing an eligible, diverse, and inclusive workforce is imperative to the future success of NASA and to our Nation. Veteran schools are encouraged to mentor and collaborate with first-time schools or schools classified as Minority Serving Institutions (MSIs). This is a means for teams to take advantage of the economies of scale as to costs, resources and overall experience. NASA will make the award to the mentor school. The distribution of work, costs, awards, etc., is an arrangement between the schools. As an example, awards to winning mentor / protégé teams would read as follows: "Grand Lakes University" in collaboration with "Faber College"

2. 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:
3. MSI Capability Gateway – https://beta.nasa.gov/learning-resources/minority-university-research-education-project/the-minority-serving-institution-msi-exchange/
4. Scientific American – https://www.scientificamerican.com/article/how-diversity-makes-us-smarter/

12. Why the Moon

With NASA's Artemis campaign, we are exploring the Moon for scientific discovery and technological advancement and to learn how to live and work on another world as we prepare for human missions to Mars. We will collaborate with commercial and international partners and establish the first long-term presence on the Moon. NASA will land the first woman and first person of color on the Moon, using innovative technologies to explore more of the lunar surface than ever before. The agency will use what we learn on the Moon to prepare for humanity's next giant leap – sending astronauts to Mars (https://www.nasa.gov/humans-in-space/artemis/#missions).

"Lunabotics is Good for NASA, Good for America, Good for All of Us."

13. The Lunabotics Awards

1. **STEM Engagement Report –** (1st - $1,000, 2nd - $500, 3rd - $500) best inspiration to study STEM-related topics in their community to include collaboration with middle school students and present a high number of quality activities to a large and wide range of audiences.

2. **Presentations and Demonstrations –** (1st - $2,000, 2nd - $1,000, 3rd - $500) present intent and technical outcome of their design project. Allows the students to develop their public speaking skills.

   Presentations and Demonstrations

   First Steps Award – Best Presentation by a First-Year Team.

3. **Systems Engineering Paper** – (1st - $2,000, 2nd - $1,000, 3rd - $500) best application of the NASA Systems Engineering process used to design, build, test, and evaluate their robot.

   Systems Engineering Nova Award for Stellar Systems Engineering by a First Year Team – awarded to the team(s) who perform exceptional systems engineering in their College/University's first year in the Lunabotics Challenge as demonstrated in their systems engineering paper.

   Systems Engineering Leaps & Bounds Award - for significant improvement over the previous year(s) in the team's application of systems engineering to develop their robot system.

4. **Lunabotics Innovation Award** – for the best design based on creative construction, innovative technology, and overall architecture.

5. **Lunabotics Efficient Use of Communications Power Award**

6. **The Caterpillar Autonomy Award –** (1st - $2,000, 2nd - $1,250, 3rd - $750, 4th -500, 5th - $250, 6th - $250) awarded by Caterpillar for successfully completing the activities autonomously.

7. **The Lunabotics Construction Award** – (1st - $2,000, 2nd - $1,000, 3rd - $500) awarded to the teams that score the most points during the berm building operations in the Artemis Arena.

8. **The Grand Prize, The Lunabotics Artemis Award –** ($5,000) The winning team shall submit the required items, complete all the events, and score the most points, a cumulative of the scores.

The Points:

1. STEM Engagement Report	15 Points
2. Systems Engineering Paper	25 Points
3. Presentations and Demonstrations	15 Points
4. Robotic Construction	25 Points

Note: This list is not all-inclusive; some are not awarded every year and are subject to change without notice.

14. Eligibility

1. The schools shall:
   Be an accredited Institution.
   Enroll one (1) team per school only.
   Be a post-high school, vocational/technical school, college, university, etc.
   Be in the United States, its Commonwealths, territories, and or possessions.

2. The students shall:
   Be 18 years old at registration.
   Be currently enrolled and in good standing with their school.
   Be from the same school as their team.
   Participate in one team.

3. The Teams shall:
   Have its own working robot(s).
   Have at least two (2) undergraduate and graduate students.
   The number of students on the team is at the school's discretion.
   Students who have graduated in the same semester/quarter as this challenge are eligible to be on the team.

4. The Faculty / Advisor (F/A) shall:
   Supervise the team as to the spirit and intent of the Guidebook.
   Be employed by the institution and authorized to represent it.
   Cannot be a part of the team.

5. For the on-site event at KSC:
   The person responsible for checking in with the team shall be 21 years old, employed by the institution, authorized to represent the institution, and remain on-site with the team until the team departs the challenge.

15. Alignment with National Standards in Engineering and Space

Lunabotics provides students an opportunity to apply the NASA Systems Engineering process in designing a prototype robot capable of performing the proposed construction operations on a simulated Lunar regolith surface. Encouraging innovation in student designs increases the potential of identifying clever solutions to the many challenges inherent in future Artemis Lunar missions. Students will develop a deeper understanding and enhance their communication, collaboration, inquiry, problem-solving, and flexibility skills, which will benefit them throughout their academic and professional lives.

The skills students develop in Lunabotics apply to other high-technology industries that rely on systems engineering principles. These industries will create a workforce posed to lead a new space-based economy and add to the economic strength of our country. Lunabotics aligns with the Accreditation Board for Engineering and Technology (ABET) criteria outlined below:

Criteria 3. Student Outcomes: For baccalaureate degree programs, these student outcomes must include, but are not limited to, the following learned capabilities:

1. an ability to select and apply the knowledge, techniques, skills, and modern tools of the discipline to broadly defined engineering technology activities;
2. an ability to select and apply a knowledge of mathematics, science, engineering, and technology to engineering technology problems that require the application of principles and applied procedures or methodologies;
3. an ability to conduct standard tests and measurements; to conduct, analyze, and interpret experiments; and to apply experimental results to improve processes;
4. an ability to design systems, components, or processes for broadly defined engineering technology problems appropriate to program educational objectives;
5. an ability to function effectively as a member or leader on a technical team;
6. an ability to identify, analyze, and solve broadly-defined engineering technology problems;
7. an ability to apply written, oral, and graphical communication in both technical and non-technical environments; and an ability to identify and use appropriate technical literature;
8. an understanding of the need for and an ability to engage in self-directed continuing professional development;
9. an understanding of and a commitment to address professional and ethical responsibilities including a respect for diversity;
10. a knowledge of the impact of engineering technology solutions in a societal and global context; and;
11. a commitment to quality, timeliness, and continuous improvement.

16. Minority Serving Institutions Program

For More Information on MSIs, visit the Department of Education Office of Postsecondary Education - Programs.

Veteran schools are encouraged to collaborate with schools classified as Minority Serving Institutions (MSIs). Building and nurturing an eligible, diverse, and inclusive workforce is imperative to the future success of NASA and to our Nation. This is a means for teams to take advantage of the economies of scale as to costs, resources and overall experience. The distribution of work, costs, awards, etc. is an arrangement between the schools. As an example, awards to winning mentor / protégé teams would read as follows: “Grand Lakes University” in collaboration with “Faber College”.

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:

Being around people who are different from us makes us more creative, more diligent, and harder working. See Scientific American ”How Diversity Makes Us Smarter” at https://www.scientificamerican.com/article/how-diversity-makes-us-smarter/

17. Applying on the STEM Gateway Website

The timeline/deadlines for all Lunabotics items are posted on the Lunabotics Website. STEM Gateway application site opens seven (7) days prior to a deadline (milestone). Deadlines are at 5:00 PM Eastern Time. Dates Are Subject to Change.

1. The number of teams accepted to this challenge is not predetermined but is based on the quality of the deliverables received and other factors. You are advised to start the application process as soon as feasible. It is your responsibility to comply with the requirements; you are encouraged to put a second set of eyes when reviewing all your work items, and you are advised not to wait until the last day or days of a deadline to upload your files. For more information on navigating the NASA Gateway OSTEM Application Website, see “Appendix A. Gateway Team Application Instructions” at the end of the Guidebook.

2. You cannot "delete" a file from the Gateway system; you can only add files. Lunabotics will review the most recent file that is received prior to the deadline. NASA reserves the right to question or reject any item if submitted by a party not authorized to represent the institution in question.

3. When you encounter an issue on the NASA Gateway OSTEM application website, send your inquiries to the website Help Desk. Responses to your inquiries may take two or three days. Do not contact Lunabotics about website issues. We do not own the website, cannot unlock your account(s), cannot troubleshoot issues, etc.

4. Most of the formal institutions in the system are sourced from nces.ed.gov, which may sometimes list a different address (just based on their own data) but is still the same institution based on other unique identifiers. If there is a discrepancy, submit your corrections to https://stemgateway.nasa.gov/public/s/contactsupport, please include the institution's name, address, website, phone, etc.

5. All email addresses shall use an ".edu" domain address. This applies to the application process and communications with Lunabotics. We can only respond to ".edu" addresses.

6. The team lead starts the application process and then invites the faculty advisor.

7. The team lead will be responsible for uploading the Application Package to the STEM Gateway Website. The following deliverables are required to apply to Lunabotics [use the following format to name your PDF files, Deliverable Name-School Name (not your team's name)]:

   Statement of Support
   SOS-School Name

   Statement of Rights of Use
   SRU-School Name

   Project Management Plan
   PMP-School Name

   The team lead will be notified of the application status.

   If your team's application has been accepted, your team lead will invite each member to register on the NASA Gateway STEM application website.

Statement of Support

A statement of support from a faculty/advisor indicating a willingness to supervise and work with the team during all stages of NASA's Lunabotics. There will be no consideration for teams working without a faculty advisor. The faculty advisor must also sign off on the cover of all deliverables as evidence they have seen the application and approves of the submission.

The following statement shall appear on an institution letterhead and include the signature of the faculty advisor:

Faculty Advisor: ____

University / College: ____

I concur with the concepts and methods by which the students plan to compete in "NASA Lunabotics". I will ensure the student team members complete all project requirements and meet deadlines in a timely manner. I understand any default by this team concerning any project requirements (including submission of final report materials) could adversely affect selection opportunities of future teams from their institution.

Signature and Date: ____

	Name (Print)	**Signature**	**Advisor/ Faculty/Student**
1			
2			
3			
4			
5			
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Statement of Rights of Use

Statements of Rights of Use - 1

These two statements grant NASA, acting on behalf of the U.S. Government, rights to use the team's technical data and design concept, in part or in entirety, for government purposes. This statement is not required. However, teams with a Statement of Rights of Use may receive greater consideration in the application selection. If choosing to include these statements, all team members and faculty advisors must sign. The statements read as follows:

Statement of Rights of Use - Agreement 1

As a team member for a(n) application entitled "NASA Lunabotics" proposed by a team of students the undersigned will and hereby do grant the U.S. Government a royalty-free, nonexclusive and irrevocable license to use, reproduce, distribute (including distribution by transmission) to the public, perform publicly, prepare derivative works, and display publicly, any data contained in this application in whole or in part and in any manner for Federal purposes and to have or permit others to do so for Federal purposes only.

University/College: ____

	Name (Print)	Signature/Date	Faculty/Student
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
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15			

Statement of Rights of Use

<u>Statements of Rights of Use - 2</u>

These two statements grant NASA, acting on behalf of the U.S. Government, rights to use the team's technical data and design concept, in part or in entirety, for government purposes. This statement is not required. However, teams with a Statement of Rights of Use may receive greater consideration in the application selection. If choosing to include these statements, all team members and faculty advisors must sign. The statements read as follows:

<u>Statement of Rights of Use - Agreement 2</u>

As a team member for a(n) application entitled "NASA Lunabotics" proposed by a team of students, the undersigned will and hereby do grant the U.S. Government a nonexclusive, nontransferable, irrevocable, paid-up license to practice or have practiced for or on behalf of the United States an invention described or made part of this application throughout the world.

University/College: ____

	Name (Print)	Signature/Date	Faculty/Student
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SECTION 2: TECHNICAL

1. RoboPits

The RoboPits are in the Astronauts Memorial Foundation's (AMF) Center for Space Education (CSE) Building, M6-306. This is where you will meet with competitors from across the country and prep your robots before heading to the Artemis Arena. The RoboPits are equipped with emergency eyewash stations and disposal containers for used aerosol cans, batteries, degreasers, and wipes used as cleaners. Teams are encouraged to bring additional LED lighting, floor coverings/mats to facilitate cleaning, power strips, and a first-aid kit to the RoboPits.

2. Check-in and Set-up

1. The Pit Boss will assign your pit, explain the inspection process, signing up for runs, and other protocols. If things get hectic, be professional.
2. Your team will be required to provide 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 deleted at the end of the competition.
3. Your pit measures 8'x10' with two chairs, one table, and two power outlets. Pits have power strips provided. Do not daisy chain power strips.
4. Each team will keep their team and equipment contained within their assigned pit and keep the walkways/hallways clear and unobstructed.
5. Vacuums are provided and are for shared use by all teams as needed. Return vacuums to the designated area.
6. Notify the Pit Boss about any safety concerns or vacuums that need cleaning.

3. Team Spirit

You are responsible for making your pit identification sign. Use common sense, and keep it fun; under 6' tall, you can use LED light strings. Remember, KSC Fire/Safety may ask you to remove it if it is outside their policy. Come up with a team cheer or chant and be creative in decorating team shirts. But definitely use your imagination and stand out!

4. Safety (robot) and Communication (comm) Inspection

1. The inspection stations will be identified.
2. The robot will have to pass the safety inspection first before moving forward.
3. The inspections are not scheduled and are on a first-come, first-served basis.
4. The Pit Boss will provide the team lead with the inspection card.
5. Return the card when you have passed the Safety and Comm checks and are ready to compete. The card is to ensure that all teams have had their robot(s) checked out prior to entering the arena.
6. Before each competition run, an escort will come to the RoboPit to retrieve the team; do not leave without the escort.

5. Preparing for the Competition Attempt

The teams will be brought to the safety inspection approximately 30-45 minutes before the scheduled start time to ensure a smooth flow. At this time up, to four (4) students will go to the personal protective equipment (PPE) prep area to don the PPE gear they will be wearing in the Artemis Arena. Following the inspection, the escort will take the team to the arena, where arena escorts will take over. If the team is not ready or cannot be located, the competition run time will be given to another team that is ready.

6. Clean-up and Check-out

The RoboPit is expected to be neat each night, with nothing outside of the pit boundaries. Unplug all items before leaving for the night. 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. 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 prior to departure.

7. Stop Work Order (SWO)

Lunabotics staff are authorized to issue an SWO to a team regarding any suspected safety issue. The team will immediately stop all activity. The Faculty Advisor must meet with the Pit Boss to resolve the issue. The SWO will remain in effect until the Pit Boss has ruled on the issue. The Pit Boss decision shall prevail.

8. The KSC Prototype Development Laboratory's (PDL) Bot Shop

The PDL is a team of KSC engineering technicians whose primary purpose is designing, fabricating, and testing prototypes, test articles, and test support equipment. This "mobile machine shop" has grinding, sanding, mini-mill and mini-lathe, band saw, drill press, and hand tools (no welding). They can help repair broken robots but do not have the capability to finish a started robot. Only PDL "Mechanics" can use the equipment. You have the privilege of using this resource to make repairs and/or modifications to your robots on a first-come, first-served basis. Protective eyewear shall be worn in the Bot Shop.

9. 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 representative items listed below (specially marked containers will be provided):

Waste Accumulation and Disposal Protocol Batteries (Alkaline, Lithium, Ni-Cd). Spray Paint. Oily wipes/IPA solvent wipes. Spray Foam. Solder Waste. Spray Adhesives. Acetone wipes. WD40. PCV cement – brushes, wipes, and cans. PB Blaster. PVC primer – brushes, wipes, cans. Silicone Spray. Super Glue (cyanoacrylates). Oil Cans. Epoxy Tubes. 3 in 1 oil. Aerosol Cans. Any as required by regulations.

10. Safety in the RoboPits and Artemis Arena (participants and other carbon-based life forms)

Lunabotics personnel (Pit Boss, Arena Chief, etc.) are authorized to rule on any safety and health issues. You are responsible for using the correct Personal Protective Equipment (PPE) for the situation. Do not wear ties, loose clothing, jewelry, hanging key chains, or similar when near or working on moving or rotating machinery to avoid the potential risk of being drawn into rotating parts. Only break-away lanyards are permitted. Use the right tool for the right job, wear gloves/gauntlets to de-energize robots and equipment as needed, bring jack-stands to support your robot instead of folding chairs, and wire strippers should be utilized instead of knives. etc. Bring your own LED lighting for your pit. Address any safety concerns to the RoboPit Chief immediately.

11. Personal Protective Equipment (PPE)

NASA will provide goggles, N-95 masks, bunny suits, rubber gloves and booties for use in the Artemis Arena. The teams are responsible for providing all other OSHA, ANSI, etc., or equivalent required PPE (see SECTION 2: TECHNICAL, 14. Eye / Face Protection, 15. Hand Protection, 16. Hearing Protection, 17. Foot Protection).

12. Regolith Simulant - Black Point-1 (BP-1)

1. Is a crushed lava basalt aggregate with a natural particle size distribution similar to lunar soil.
2. It is alkaline and may cause skin and eye irritation.
3. If you are allergic to talcum powder, it is a good indication that you may be allergic to the BP-1. Participants are required to don Personal Protective Equipment (PPE) before coming into contact with the BP-1.
4. BP-1 contains a small percentage of crystalline silica, which is a respiratory nuisance. Respiratory protection shall be used.
5. All PPE must be ANSI-approved, UL-Listed, CE EN166 rated, AS/NZS certified, or CSA rated, as applicable. The following describes the common PPE that you are required to wear.

13. Respirators

1. OSHA1926.1153 – Respirable Crystalline Silica, 29 CFR 1910.1053. Permissible exposure limit (PEL). The employer shall ensure that no employee is exposed to an airborne concentration of respirable crystalline silica in excess of 50 μg/m3, calculated as an 8-hour TWA.
2. The Respiratory Protection standard, paragraph 29 CFR 1910.134(g)(1)(i)(A), states that respirators shall not be worn when facial hair comes between the sealing surface of the facepiece and the face or that interferes with valve function. Facial hair is allowed as long as it does not protrude under the respirator seal or extend far enough to interfere with the device's valve function.
3. OSHA – has not exempted any workers for religious reasons; however, we recognize that if such a situation should arise, there are respiratory protection alternatives, such as loose-fitting hoods or helmets that will accommodate facial hair.
4. OSHA – workers cannot sign a waiver to be exempted from the stated requirements. A release or waiver is not possible for employees. That being said, when a(n) employer is looking to accommodate a religious practice, they

may have to explore respiratory protection alternatives like helmets or loose-fitting hoods.

5. Most N95 respirators are manufactured for use in construction and other industrial-type jobs that expose workers to dust and small particles. They are regulated by the National Personal Protective Technology Laboratory (NPPTL) in the National Institute for Occupational Safety and Health (NIOSH), which is part of the Centers for Disease Control and Prevention (CDC). NIOSH-approved N95 Particulate Filtering Facepiece Respirators are required in the Artemis Arena.
6. There are very few options, but the best choice would be for the individual to purchase a hooded-powered air purifying respirator (PAPR) – especially if they intend to stay in a career that requires the occasional use of PPE. These items shall be provided by the institutions for their participants if required.

14. Eye/Face Protection

1. Without exception, protective eyewear must be worn in the individual pits, the Bot Shop, and Artemis Arena.
2. It is also a good practice and principle to wear eye protection in the following situations:
   - Any area posted with signs requiring the use of eye protection (such as the Bot Shop).
   - When performing any work on the robot, including grinding, drilling, soldering, cutting, welding, etc.
   - When there is a risk of flying particles or chemical exposure (such as splashes, splatters, and sprays).
   - Several forms of eye/face protection are available to provide protection from related hazards, including safety glasses with side shields, goggles, face shields, and face masks.
   - Safety Glasses and protective eyewear are designed to provide a shield around the entire eye to protect against hazards such as splashes of liquids, burns from steam, compressed air, and flying wood or metal debris. To prevent injury, all individuals in the pit area, the practice field area, and the arena must wear safety glasses or protective eyewear that is ANSI-approved,
   - Reflective lenses are prohibited; your eyes must be clearly visible to others. Accommodations will be made for participants that require tinted safety glasses.
   - Prescription Glasses: If you wear prescription glasses that do not have a marked safety rating, you must wear rated safety goggles over them to achieve adequate protection. If you wear marked safety-rated glasses, you may use ANSI-approved
   - Safety-rated glasses, side shields, and frames can be identified by markings stating the standard that they are rated to (ex. Z87.1).

15. Hand Protection

Hand protection protects against heat, electrical, chemical, laceration, and mechanical hazards. Use proper gloves and mechanical tool guards for the application. Selected the correct one to use for each activity.

16. Hearing Protection

Provide and use hearing protection devices, such as earplugs, where there are objectionable/questionable sound levels.

17. Foot Protection

Participants must wear shoes that completely cover the entire foot. Shoes must be substantial and have closed toes and heels to protect against foot injuries, regardless of work location. Flip-flops, sandals, mules, lightweight slippers, etc., are unacceptable when working on or near the robot. Safety shoes or toe guards are sometimes appropriate for areas where heavy objects can fall on your foot.

18. Clothing Allowed

Shirts/tops that cover the upper torso. Long pants that cover the wearer to the ankle. Completely enclosed shoes that cover the instep of the foot, preferably leather, which can be wiped clean. Baseball caps and other headgear as long as they are kept far enough back on the head so that vision is not impaired and do not interfere with protective eyewear.

19. Clothing Not Allowed

Hair must not impede vision or come in contact with the work. Hair must be kept away from the eyes. Long hair must be tied back. Hair longer than 6 inches from the nape of the neck must also be pinned up (use of hair nets or hats is acceptable). Flowing garments and neckwear such as ties and scarves that hang loose. Caps worn low over the eyes so as to impede vision. Cropped shirts, plunging necklines, spaghetti straps, or ripped shirts.

Ripped jeans, shorts, capris, or skirts. Loose or flowing tops with wide/bell sleeves, outerwear such as coats or shawls. Sandals, open-toe, open-back, or open weave shoes, and shoes with holes in the top or sides that will expose the skin to regolith or retain regolith.

20. Spectators

Should follow the same rules as participants. If substantial close-toed shoes are not available, they may enter the pit area as long as they remain in the pit aisles. Spectators who do not meet the footwear requirement for participants, as described above, are not allowed inside individual team pits or in any locations where robots are being worked on.

21. Personal Protective Equipment (PPE) DONN / DOFF

1. Personal protective equipment (PPE) is an important element to help ensure participants are protected from hazards in the work area. The PPE Attendant will ensure that participants are provided with the correct PPE for the task they are performing. The following describes the common PPE that you are required to wear.
2. PPE is required to place the robot in the Artemis Arena, Room 9010, for (participants) and during robot operation/disturbance of regolith material (judges/regolith assistants).
3. Participant PPE - includes N-95 Filtering Facepiece, full body protective suits with hood and booties, and nitrile gloves when entering the Artemis Arena.
4. Judges/Regolith Assistants PPE - inside the arena during robot operation includes full face Respirator with P100 filters or full-face powered air purifying respirator (PAPR), full body protective suits with hood and booties, rubber boots, and nitrile gloves.

22. Donning Protocol

1. **Participant**
   - Select the appropriate size Tyvek coverall suit and put it on over shoes
   - Select appropriate gloves and don them, overlapping the Tyvek suit.
   - Tape gloves to the Tyvek coveralls overlap to ensure skin is not exposed.
   - Tape may also be applied above the ankles and waist to contain excess Tyvek coverall material.
   - Place N-95 filtering face piece over nose and mouth. Adjust the nose bridge to obtain a comfortable fit and prevent eye protection fogging.
   - NOTE: Without exception, proper use of such masks and/or respirators shall require a clean-shaven face as determined by the Competition Staff.
   - Place dust goggles over eyes and cover head with Tyvek suit hood.
2. **Judges / Assistants**
   - Full-face negative pressure respirator with P-100 filters or full-face powered air purifying respirator (PAPR) and cover head with Tyvek suit hood.
   - Don rubber boots over Tyvek booties if working in the regolith pit.

23. Doffing Protocol in the Artemis Arena After completion of the Robot Run

1. Remove the hood, then remove the Tyvek coverall rolling down from the inside of the suit.
2. Remove gloves taped to suit. Place coveralls in a designated waste container:
3. Participants: Remove eye protection and return to PPE attendant.
4. Remove N-95 filtering facepiece and discard.
5. Judges: Shall maintain their PAPR equipment IAW the manufacturer's specifications.

ARTEMIS ARENA SPECIFICATIONS AND PROTOCOL


Photo 1: Artemis Arena External View

1. Artemis Arena Specifications

1. The Artemis Arena at KSC is filled with Black Point-1 (BP-1) crushed basalt rock lunar regolith simulant.
2. The arena area measures ~6.8 m long and ~5.0 m wide (these are internal measurements between the ducts located on the inside of the arena, see Photo 2: Artemis Arena Internal View).


Photo 2: Artemis Arena Layout

3. The Artemis arena contains ~45 cm depth of BP-1.
4. Larger rocks may also be mixed in with the BP-1/gravel in a random manner (gravel is ~2cm in diameter).
5. **Obstacle Zone** - the judges will attempt to construct the obstacle field in such a way as to require obstacle detection, mapping, and navigation planning to determine a “slalom” route to reach the excavation zone.
6. **Boulder Obstacles** - there will be at least three (3) obstacles placed on top of the arena surface within the obstacle zone area before each competition attempt is made. The placement of the obstacles will be randomly selected before the start of the competition. Each obstacle may have a diameter of approximately 30 cm to 40 cm and will have random heights. There may be boulders in the excavation zone, these will not exceed the dimensions of any in the obstacle zone.
7. **Crater Obstacles** - there will be at least three (3) craters of varying depth and width, being no wider or deeper than 40 - 50 cm in the obstacle zone.
8. **Infrastructure Obstacle** - arena has a central support structure column which is an obstacle and must be avoided.
9. The Artemis Arena includes ducting that goes around the perimeter, as shown in Photo 2: Artemis Arena Internal View, this duct is 17cm in diameter.
10. Mounting of Beacons for Navigation – information to be posted as an FAQ

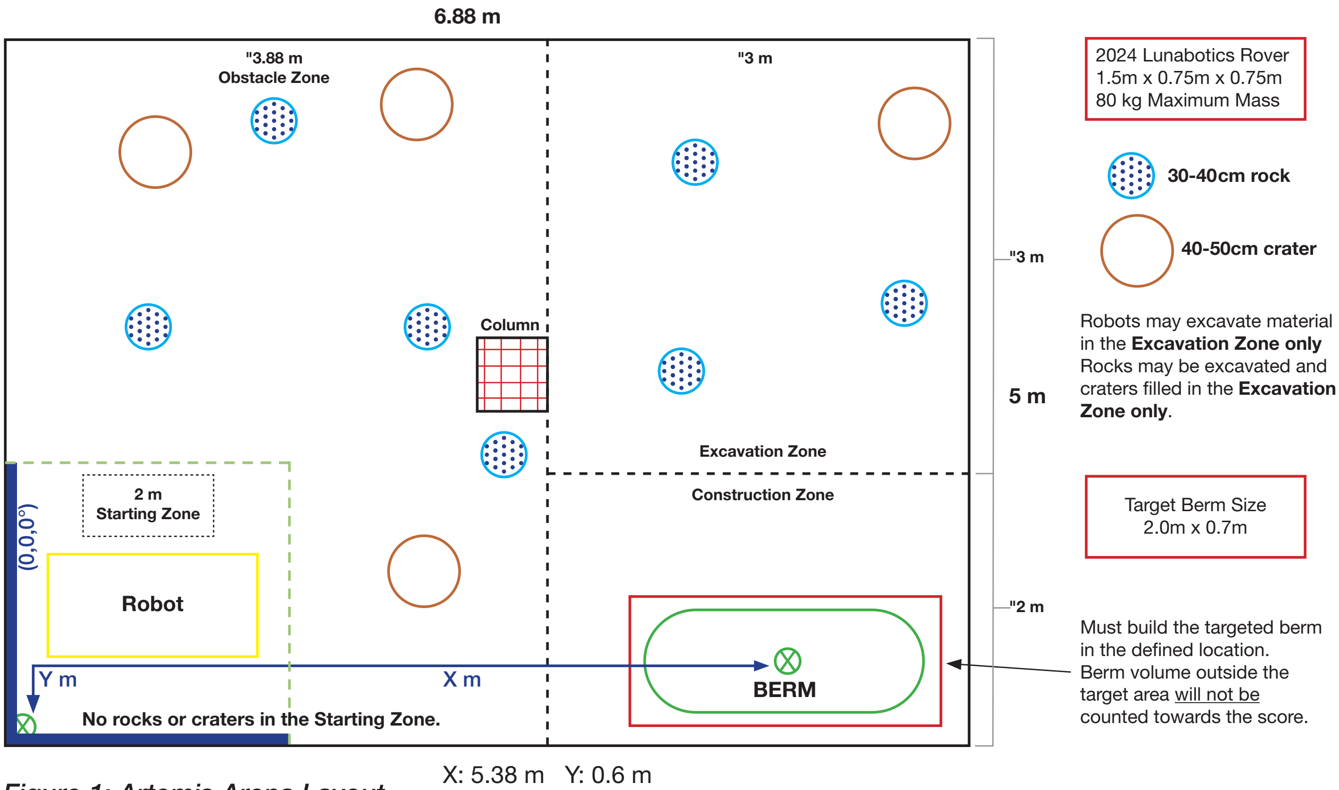


Figure 1: Artemis Arena Layout

2. Artemis Arena Protocol

1. Once competition runs begin, the Artemis Arena is considered an operational area with restricted access.
2. Students shall follow the instructions of the Arena Chief and Arena personnel promptly.
3. Faculty / advisors are not permitted in the Artemis Arena during the competition.
4. Access is restricted to currently active competing team members only. If the team's robot is not in the arena or arena staging area, team members are not permitted in the Artemis Arena.
5. The Artemis Arena is defined as all areas within room 9010/9020 of building M6-306 (Center for Space Education) at Kennedy Space Center Visitor Complex. The Arena staging area, Competition Arena, HEPA station, and Arena Chief's station are located within the Artemis Arena.
6. For Arena operations, the currently active competing team members are defined as the team members attired in PPE that are tasked with placing the robot in the arena during the setup period and removing the robot from the arena after the run has ended (max of 4 people) and the corresponding Mission Control team members (max of 4 people).
7. Photography and personal electronic devices (smart devices, tablets, cell phones, etc.) will be restricted in the Artemis Arena.
8. Team members placing the robot in the Competition Arena will don PPE in the RoboPits staging area.
9. When properly attired, they and Mission Control teammates will be escorted to the Artemis Arena entrance.
10. The Arena Chief will grant access to Artemis Arena staging area when ready.
11. Student cell phones, cameras, tablets, and other restricted electronics devices brought into the Artemis Arena shall be placed on the Arena Chief's station to be retrieved later. No exceptions.
12. Team members will be given a Pre-Task Briefing (PTB) containing specific information needed for the run.
13. At the end of the PTB, the Mission Control team members will immediately exit the Arena staging area and proceed directly to the Mission Control staging area.
14. Team members in PPE shall remain with their robot in the designated Arena staging area until directed otherwise by the Arena Chief or designated representative.
15. Approaching the Competition Arena before instructed to do so by the Arena Chief or designated representative is not permitted.
16. The Arena Chief will inform the team members in the staging area when the Competition Arena is ready for the team.

Participants viewing the construction attempt.

17. At the direction of the Arena personnel, the team members will place their robot in the Arena and perform setup activities necessary to establish communication with Mission Control. The construction robot will be placed in the arena in a randomly selected starting position and direction. Assume there are positive and negative obstacles. Assume you cannot drive over the obstacles.
18. When complete or directed by Arena personnel, the team members will promptly exit the Arena.
19. Only the team members in PPE may observe the competition run from a designated area in the Arena. The team members must remain in the designated area for the duration of the run.
20. Photos may be permitted during this time at the discretion of the Arena Chief. Photos are limited to the construction zone and berm construction. It may be that only the final berm configuration may be photographed. Photos, if permitted, shall be taken by a single designated individual using a single device (i.e. cell phone, tablet, or camera) retrieved from the Arena Chief's station. Any photos taken shall not be shared, posted, or transmitted in any way while the team members are in the Artemis Arena. Violation of this rule may result in team disqualification.
21. When the competition run has ended, the team members in PPE shall promptly retrieve their robot and equipment from the Arena and proceed to the HEPA station.
22. At the HEPA station, team members shall:
    1. Vacuum excess BP-1 from their robot.
    2. Doffing Protocol in the Artemis Arena After completion of the Robot Run
        - ❖ Remove hood then remove Tyvek coverall rolling down from inside of suit.
        - ❖ Remove gloves taped to suit. Place coveralls in designated waste container:
        - ❖ Participants: Remove eye protection and return to PPE attendant.
        - ❖ Remove N-95 filtering face piece and discard.
        - ❖ Judges: Shall maintain their PAPR equipment IAW the manufacturer's specifications.
        - ❖ Properly discard all used PPE.
        - ❖ Return goggles for cleaning and reuse.
        - ❖ Remain in the HEPA area until directed to exit the Artemis Arena by the Arena Chief or designated personnel.

23 Remember, the Artemis Arena is an operational area during competition days. There are many activities occurring in series and in parallel. It is very important that everyone in the Arena practice situational awareness at all times.

ROBOTS AND ROBOTIC OPERATIONS

1. Robots

1. Lunar bulk regolith construction requires teams to consider several design and operation factors such as high robot dust tolerance and minimizing dust projection, efficient communications, minimizing vehicle mass, minimizing energy/power required, and maximizing autonomy. Each team will have the opportunity to complete two construction competition runs to demonstrate their design.
2. Students on the team shall perform 100% of this project (including design, construction, and task components of their vehicle and deliverables, and including performing or supervising work that is supported by a professional machinist for the purpose of training or safety). Components (i.e. electronic, mechanical, etc.) are not required to be space qualified for atmospheric, electromagnetic, thermal, or Lunar environments.

2. Robot Requirements

1. Volumetric dimensions - robot(s) shall be contained within a payload envelope measuring 1.50 m length x 0.75 m width x 0.75 m height. The orientation of these dimensions may be chosen by the team. It may deploy or expand beyond the envelop after the start of each attempt but shall not exceed 1.75 m in additional height (which is 2.5 m above the surface of the regolith). Multiple robot systems are allowed but the starting dimensions of the whole system (all the robots) shall comply with the volumetric dimensions given in this rule.
2. Robots will be inspected for the volumetric dimensions in the stowed configuration during the Safety Inspection. A “jig” frame will be placed over the rover for volume constraint verification. No modifications or team robot interaction is permitted during this verification.
    - Robot Mass - a maximum mass of 80kg. Subsystems/equipment on the robot that are used to transmit commands / data and video to the telerobotic operators are counted toward the mass limit.
    - The mass of the navigational aid system, including any beacons or targets not attached to the robot, is included in the maximum mining robot mass limit of and must be self-powered.
3. 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. Multiple robot systems are allowed but the total mass of the whole system shall comply with the mass given in this rule. The commercial cost of delivering payloads to the Moon is about $1.2 Million per kg (estimate). This competition aims to simulate a Lunar mission where a robot is delivered to the Moon. This corresponds to an approximate mission cost of $72 Million. Lower masses will result in lower mission costs so this competition rewards teams that have a lower robot mass.
4. External robot antennas are required to reduce potential interference problems.
5. Robots shall have a minimum of four (4) lifting points, safe for human hands and clearly marked (ISO 7000-1368) for students and staff to use. Teams are responsible for placement and removal of their construction robot onto the BP-1 surface. There must be one person per 20 kg of mass of the construction robot, requiring a minimum of four people to carry the maximum allowed mass of 80 kg.
6. The robot can separate itself intentionally, if desired, but all parts of the robot must be under the team’s control at all times. Unintentional breakage will not be counted against the team. The robot does not have to re-assemble prior to the end of the competition run.
7. The robot can run either by telerobotic (remote control) or in autonomous operations and cannot have any touch sensors to sense and avoid obstacles.
8. Reference Points / Reference Arrows - The launch volume dimensions of the robot may be oriented in any way (length, width, height can be defined along any of the X, Y, Z axes, dimensions correspond to the typical payload volume available on today’s Lunar landers).
    - The team must declare the robot orientation by length (arrow 1) and width (arrow 2) to the inspection judge. Reference Point (arrow 3) - must mark the forward direction of the mining robot in the starting position configuration (the reference location and arrow pointing forward can point any direction of the team’s choosing, except up or down). 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.
    - 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 if multiple arrows do not conflict.

3. E-STOP Button

1. Also known more formally as an emergency brake, emergency stop (E-stop), emergency off (EMO), kill switch, or emergency power off (EPO), is a safety mechanism used to shut off machinery in an emergency, when it cannot be shut down in the usual manner.
2. OSHA and relevant standards such as IEC 60204-1 state that an e-stop must be readily accessible to the operator.

Additionally, it should be unobstructed—no collars or actuation restrictions—and easily accessible without having to reach over, under or around to actuate. Machine-building standards such as ANSI B11, B11-19 and National Fire Protection Agency (NFPA) 79 also address specifics in regard to safety devices such as an e-stop.

3. OSHA and relevant standards such as IEC 60204-1 further state that resetting of the e-stop alone shall not resume operation. A second deliberate action is needed, such as the pressing of a reset button. This could include twisting the mushroom button and allowing it to spring back up or pulling the button back up to reset. It cannot automatically reset.
4. The robot shall be equipped with an E-STOP button. An unmodified "Commercial Off-The-Shelf" (COTS) red button is required. Use sound engineering practices and principles in placing and securing the E-STOP button on your robot(s), failure to do so may result in a safety disqualification. The E-STOP button shall have a minimum diameter of 40 mm and require no additional steps to access it.
5. The E-STOP button shall be placed on the highest practical location on the robot. There shall be only one E-STOP button per robot and in the case of multiple robots, each robot shall have its own E-STOP button
6. Disabling the E-STOP button without authorization from the Staff shall result in a safety disqualification.
7. The E-STOP button shall stop the construction robot's motion and disable power with one push motion on the button. It shall be reliable and instantaneous. 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 safe the construction robot in the event of a fire or other mishap. The button shall disconnect the batteries from all controllers (high current, forklift type button) and it shall isolate the batteries from the rest of the active sub-systems as well.
8. Only onboard laptop computers 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 E-STOP button.

4. Power Meters / Data Loggers

1. The robot shall provide its own onboard power. No facility power will be provided to the robot during the attempt. There are no power limitations except that the robot must be self-powered and included in the maximum mass limit. Shall be schematically located between the battery and kill switch, so the readings are not erased if the E-STOP button is activated. The devices shall be placed on the highest practical location on the robot and be easily visible.
2. The energy consumed shall be recorded with a "Commercial Off-The-Shelf" (COTS) electronic data logger device. Actual energy consumed during each attempt shall be shown to the judges on the data logger immediately after the attempt ('immediate' includes time for 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.

5. Battery Protocol

1. This for the Lithium-Ion / Nic-Cad batteries used in your robots.
2. Batteries must be attended while charging. Chargers shall be unplugged overnight.
3. Battery containers must be designed for safely storing, charging, and transporting lithium-ion batteries, or approved equivalent.
4. Batteries must be stored in upright containers; batteries cannot be in contact with each other.
5. Batteries that have been dropped must be inspected for damage and replaced as needed.
6. Do not store batteries that are hot to the touch after charging.
7. If a battery continues to feel hot after charging, if possible, remove from the building and place outside and notify NASA Fire as a non-emergency issue.
8. No one will fault you if in your opinion you need to call NASA Fire at 321.867.7911.
9. 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.
10. The rules are intended for 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 LHS-1 & BP-1 regolith simulant is very dusty and abrasive

11. Teams may use honeycomb structures as long as they are strong enough to be safe and the edges sealed to prevent dust intrusion, a wheel with a large honeycomb structures that is open on both sides is allowed as long as the edges are not so sharp that they would be a cutting hazard.
12. 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. This will not pass inspection,

6. Robotic Operations

1. The robot cannot be anchored to the sand prior to the beginning of the proof of life demonstration.
2. At the start of the competition run, the mining robot may not occupy any location outside the defined starting position in the regolith arena.
3. The robot must operate within the regolith arena; it is not permitted to pass beyond the confines of the outside perimeter of the arena or hit the walls during the competition run.
4. The robot may not use any process that causes the physical or chemical properties of the regolith simulant to be changed or otherwise endangers the uniformity between competition attempts. The mining robot may not penetrate the regolith simulant surface with more force than the weight of the mining robot before the start of each competition attempt.
5. No ordnance, projectile, far-reaching mechanism, etc. may be used. The mining robot must move on the regolith simulant surface.
6. Far-reaching mechanism in this context does not include any deployed or extended component as allowed in the dimensions rule above, those will not violate this rule.
7. Beacons or fiducial targets may be attached to the designated arena frame area for navigation purposes only. The designated area is anywhere on the bin frame structure along the perimeter of the starting zone (2 sides). Tape, clamps, or rods pushed into the regolith may be used, but screws or other fasteners requiring holes may not be used. This navigational aid system must be attached during the setup time and removed afterwards during the removal time.
8. The 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 responsible faculty member for "eye-safe" lasers.

Figure 1: Beacon Mounting locations
(note: the ducts along the sides of the Arena walls are 17cm diameter).

SCORING, CONSTRUCTION, NAVIGATION

1. Scoring

1. UCF & KSC – The berm construction scores from each run will be added together for the final store (final score will be cumulative, not the highest of the two attempts, not an average of the two attempts).
2. KSC Only – The teams with the first, second, and third most construction points will receive up to 25, 20, and 15 points, respectively towards the grand prize. Teams not winning first, second, or third place in the construction category can still earn one bonus point towards the grand prize for every 0.2 cubic meters of berm constructed up to a maximum of ten points.
3. These are the overall scoring elements and their approximate weightings:

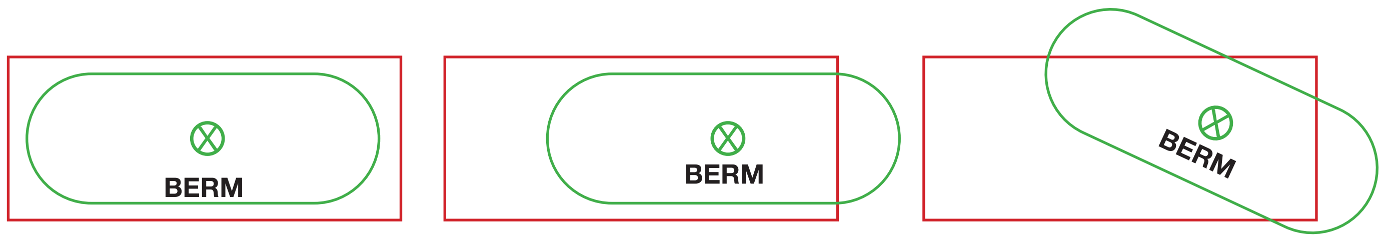
Scoring Element	Approximate Weight
Construction – Berm Productivity Normalized for Robot Mass (BP Mass)	30%
Construction – Berm Productivity Normalized for Energy Consumption (BP Energy)	20%
Autonomy	30%
Camera Bandwidth Use	10%
Dust Tolerant (Design)	5%
Dust Operation	5%

2. Construction Points:

1. **Pass All Inspections (Comm/Vehicle) -** each team is required to perform a mechanical inspection and communications check prior to the first competition run. This should be performed as early as possible after check-in to ensure compliance to all rules and communication functionality. Neither is optional, if one cannot pass, the robot will not be permitted in the Arena.
2. **Construction Berm Productivity – Normalized for Robot Mass (BP Mass) –** A volumetric scan before and after the run will be performed. Only the berm volume within the target berm location will be counted. The team will earn construction points for each cubic cm of berm constructed above grade per minute per each kg of the robot's mass. Only the portions of the constructed berm within the target area for berm placement will be counted. The target area has perimeter dimensions of 2.2 M x 0.9 M. There is no restriction on the shape, height, or number of berms constructed.
3. **Construction Berm Productivity – Normalized for Energy (BP Energy) -** A volumetric scan before and after the run will be performed. Only the berm volume within the target berm location will be counted. The team will earn construction points for each cubic cm of berm constructed above grade per minute per each w*hr 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.
4. **Camera bandwidth Use -** During each competition attempt, the team will be scored on camera usage as follows: 0 cameras = 120, 1 camera = 60, 2 cameras = 0 points.
5. **Dust Tolerant Design -** During each competition attempt a team can earn up to 60 points for dust tolerant design features on the construction 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 and performance during the competition run. The points for dust-tolerant design are as follows:
   - Drive train and components enclosed/protected: 20 points
   - Active dust control (brushing, electrostatics, etc.): 20 points
   - Custom dust sealing features (bellows, seals, etc.): 20 points

6. **Dust Free Operation -** During each competition attempt, a team can earn up to 60 points for dust free operation. The judges will allocate these points based on actual performance during the attempts. If the construction robot has exposed mechanisms where dust could accumulate during a lunar mission and degrade the performance or lifetime of the mechanisms, then fewer Construction points will be earned in this category. If the construction robot raises a substantial amount of airborne dust or projects it due to its operations, fewer construction points will be earned in this category. Ideally, the construction robot will operate in a clean manner without dust projection, and all mechanisms and moving parts will be protected from dust intrusion. All decisions by the judges regarding dust tolerance and dust projection are final. The points for dust-free operation are as follows:

    - Driving without dusting up regolith (10 points)
    - Digging without dusting up regolith (40 points)
    - Transferring regolith without dumping the regolith on your own robot (10 points)



	KSC	UCF
Berm Size	2.0m x 0.7m	1.3m x 0.7m
Target Berm Area	2.2m x 0.9m	1.5m x 0.9m

Figure 4: Artemis/UCF Arena Layout 2 - Berm Positioning

(Note 1: only the green actual berm volume inside the red box will count towards the berm volume measurement)

3. Construction Points Calculator

Example actuals based on a 30-minute run at KSC (UCF runs are based on 15-minute runs).

Construction Points Calculator – Artemis Arena

Construction Category Elements	Units	Specific Points	Example Actuals	Example Points
1. ***Pass All Inspections (Comm/Vehicle)***.	Pass = Run / 0=Default		1	**Allowed to Run**
2. ***Berm Construction Productivity – Normalized for Robot Mass (BCP Mass)*** – A volumetric scan before and after the run will be performed. Only the berm volume within the target berm location will be counted. The team will earn construction points for each cubic cm of berm constructed above grade per minute per each kg of the robot's mass.	cm^3 berm / min / kg robot mass	4.4	77551 cm^3 / 15 min run / 66 kg **78.33**	**344.6**
3. ***Berm Construction Productivity – Normalized for Energy (BCP Energy)*** - A volumetric scan before and after the run will be performed. Only the berm volume within the target berm location will be counted. The team will earn construction points for each cubic cm of berm constructed above grade per each w*hr 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.	cm^3 berm / min /watt-hour	1.5	77551 cm^3 / 15 min run / 36 whr **143.6**	**215.4**
4. ***Camera Bandwidth Use*** – During each competition attempt, the team will be scored on camera usage as follows: 0 cameras = 120, 1 camera = 60, 2 cameras = 0 points.	# cameras	120, 60, 0	1	**60**
5. ***Dust Tolerant Design*** – see description				**60**
6. ***Dust Free Operation*** – see description				**51**
7. ***Autonomy*** – See Construction Points – Autonomy	task	150, 200, 350, 450, or 600	150.00	**150.00**
8. ***Total Points***				**901**

4. Construction Protocol

1. The robot will be inspected before each competition attempt. Teams will be permitted to repair or otherwise modify their robots while the RoboPits are open.

2. Teams are responsible for the placement and removal of their robot onto the arena surface. There shall be one person per 20 kg of mass of the robot, requiring a minimum of four people to carry the maximum allowed mass of 80 kg. Assistance will be provided if needed.

3. Each team is allowed **up to** 10 minutes to place the construction robot in its designated starting position within the arena and perform required setups from MCC, and 5 minutes to remove the robot after the attempt has ended as directed by the Construction Judges.

4. The robot's starting direction and location will be randomly selected immediately before the competition attempt.

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

6. The robot shall move from the starting area, across the obstacle zone, and into the excavation zone. The robot shall not acquire regolith simulant for the berm from inside the starting area, obstacle zone, or construction zone. All regolith simulants for berm construction must be acquired from the excavation zone.

7. The robot shall not push or move any obstacles in the obstacle zone.

8. The obstacles may only be pushed to the side of the arena in the construction zone.

9. The robot shall avoid the craters in the obstacle zone (it shall not fill in any craters).

10. The robot may start excavation operations as soon as any part of it crosses into the excavation zone.

11. The robot may start construction operations as soon as any part of it crosses into the construction zone.

12. The robot shall operate within the arena; no part of it is permitted to pass beyond the confines of the outside wall of the arena during each competition attempt.

13. The robot can separate itself intentionally if desired, but all parts of the construction 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.

14. The robot **shall not**:
    - be anchored to the arena surface prior to the beginning of each competition attempt.
    - ram the wall (may result in a safety disqualification for that attempt).
    - use any aspect of the arena (wall, structure, column, etc.) in attempting any operations.
    - use any process that causes the physical or chemical properties of the regolith simulant to be changed or otherwise compromises the uniformity between attempts.

15. Bulldozing (i.e. pushing a pile of dirt/rocks) with a bladed dozer-type of rover is considered an acceptable excavation and regolith simulant transfer technique for the Lunabotics challenge. In this case, the robot would push material from the excavation zone into the berm area to create the berm. All regolith simulant material must be pushed in a pile from the excavation zone into and through the construction zone to the berm. Regolith simulant may be skimmed from the construction zone, but only if it is part of the operation of pushing it from the excavation zone into the berm (it may not be intentionally collected in the construction zone). The bulldozing pushing operation shall not start inside the construction zone – each bulldozing attempt shall start in the excavation zone.

16. Obstacles that are moved from the excavation zone into the target area will count towards these dimensions.

17. The robot shall end operations immediately when the power-off command is sent and/or as instructed by the Construction Judge. After the official competition run ends, the regolith judge will determine if the robot needs to move prior to being removed. The judge will instruct the team members when they can enter to remove the robot after ensuring that the lidar scan of the berm has been completed.

5. Navigation Protocol

1. 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 construction robot in the starting position configuration. The judges will use this reference point and arrow to orient the construction 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).

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

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

4. The mass of the navigational aid system is included in the maximum construction robot mass limit of 80.0 kg and must be self-powered.

5. Target Beacons – beacons may be attached to the provided mounting system in the starting area. The beacons may be mounted on rods pushed into the regolith at the starting area for anchoring.

6. The target/beacon may be a passive fiducial, or it may send a signal or light beam or use a laser-based detection system which has not been modified (optics or power). Only Class I or Class II lasers 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 construction 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. During each competition attempt, the construction robot is limited to autonomous and telerobotic operations only.

6. Autonomy Rules:

1. Telemetry to monitor the health of the construction robot is allowed during the autonomous period. Teams will need to remain "hands free" during any attempts at autonomy points. Teams shall explain to the inspection/ 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.

2. Teams shall not touch the controls during the autonomous period. Orientation data cannot be transmitted to the construction robot in the autonomous period. See complete details in the Mission Control Center (MCC) and Autonomous Operations.

3. The walls shall not be used for the purposes of mapping autonomous navigation and collision avoidance (there are no walls on off-world locations). Touching or having a switch sensor spring wire that may brush on a wall or any other surface as a collision avoidance sensor is not allowed (this includes touch sensors). Teams shall not use the walls of the construction arena for sensing by the robot to achieve autonomy.

4. 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 in off-world locations, and teams shall operate as closely as possible in that scenario of operations). Integrity is expected of all team members and their faculty advisors.

5. 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.

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

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

MISSION CONTROL CENTER AND AUTONOMOUS OPERATIONS

1. Mission Control Center (MCC)

Teams will control or autonomously operate their robot from the MCC to simulate operations of a Lunar In-Situ Resource Utilization (ISRU) construction mission. Lunabotics Mission Control Judges (MCJs) will supervise team activities in the MCC and assess their performance during each competition run. A Mission Control Director (MCD) will serve as the Lead Judge for the MCC to maintain the integrity of the MCC rules in the Lunabotics guidebook and ensure they are interpreted and enforced equally for all teams.

1. **General Guidelines**
    1. Each team will be allowed a maximum of 4 team members in the MCC. All members must enter the MCC together when authorized by the MCJ.
    2. Faculty/Advisors are not permitted in the MCC at any time.
    3. Teams are responsible for ensuring they enter the MCC with all mission-critical components and spares they require that are not explicitly identified in the rules and rubrics. as provided by Lunabotics. Once in the MCC, team members will not be permitted to retrieve forgotten items.
    4. Teams may only bring electronic devices required for robot operations into the MCC. Extraneous laptops, cell phones, smart devices, etc., are prohibited.
    5. Teams that have entered the MCC are not allowed any external communications until the completion of their run. The one exception is communication with their Artemis Arena teammates during the setup period, which is only permitted using equipment provided by Lunabotics.
    6. Teams must resolve all questions and rule clarifications pertinent to a competition run before entering the MCC for that run. The competition schedule will not be delayed accommodating last-minute requests of this nature.
    7. MCJs are observers only and are not allowed to provide “help” during robot operations. Mid-run questions, such as whether the robot is in an acceptable position or if certain points have been attained, will not be answered.
    8. The Mission Control and Arena judges have the authority to terminate a setup period or competition run at any time if the team is not using them in accordance with the rules and rubrics.
    9. Teams are expected to conduct themselves in a professional manner as if executing a NASA operation.
    10. Teams are expected to use sound engineering practices and principles to operate their robot.
    11. Team members must comply with all directions from the MCJ.
    12. Disputes with MCJ direction or decisions must be elevated through the MCD.
    13. Violation of the intent of a rule is a violation of the rule itself. A team found in violation of the rules and rubrics, exhibiting unprofessional behavior or unsportsmanlike conduct, or not following the directions of the Lunabotics staff may be assessed penalty points, disqualified from a competition run, or disqualified from the entire Lunabotics Challenge.

2. **Mission Setup**
    1. Teams may not connect or interact with any equipment in the MCC until the setup period begins.
    2. The setup period is for placing the robot in the Artemis Arena and bringing it online for the competition run. Teams are allowed up to 10 minutes to connect their laptops and routers, establish communications with their robot, and perform any initial systems checkout required. Teams must indicate competition readiness to the MCJ as soon as their robot is ready.
    3. During the setup period, the MCJ will provide the team with a handheld radio to enable communications with team members in the Artemis Arena. This radio will be returned to the MCJ at the end of the setup period and may not be used during the competition run.
    4. Arena team members are prohibited from pointing out obstacles, craters, and other arena conditions to the MCC team members.
    5. Teams may use the situational awareness cameras during the setup period without penalty.

3. **Mission Operations**
    1. Teams are allowed 30 minutes per competition run under nominal conditions.
    2. Telerobotic operators will have access to two situational awareness cameras in the construction area in the Artemis Arena via monitors provided in the MCC. The use of these cameras will result in a point deduction. The MCC monitors provided for situational awareness may not be utilized by the team for any other purpose.
    3. Telerobotic operators are only allowed to use data and video originating from the robot and the competition video monitors.
    4. It is the sole responsibility of team members in the MCC to communicate effectively with the MCJ to ensure

every autonomy attempt is recognized and scored correctly. If the judge Is not notified of the attempt in advance of the team initiating its execution, the score will be zero points. Teams should:

- Clearly announce and make eye contact with the MCJ when they are going to autonomous operations.
- Clearly announce when autonomy has begun and has been completed each time they trigger an autonomy cycle.

5. All autonomy attempts must be "Hands-Free", meaning no team members are permitted to touch any components (e.g., laptops, game controllers) brought into the MCC until the team has declared autonomy completion or autonomy failure.
   - If a team member interacts with any equipment while the robot is still moving or before the team has declared the autonomy attempt complete, the team will receive zero points for the attempt.
   - In the event of an autonomy failure, the team shall announce that the attempt has failed before resuming manual control.
   - Manipulation of the NASA situational awareness cameras, if in use, is permitted during autonomy attempts.

4. **<u>Mission Anomolies</u>**
   1. Once the competition timer has started, the robot has 5 minutes to move on the mission. If the robot has not moved by the 5-minute mark, the robot is considered inoperable, and the run will end.
   2. As responsible engineers, the team should notify the MCJ that they are ending the run if their robot experiences an unrecoverable issue that renders it incapable of executing key mission tasks. Such failures include:
      - Loss of Comm: The robot is functional but can no longer communicate properly with the MCC.
      - Loss of Locomotion: The robot ceases movement or experiences infrequent, non-continuous movements for a period of 5 minutes.
      - Loss of Excavation: The robot can no longer acquire regolith per its design.
      - Loss of Deposition: The robot can no longer offload regolith per its design.
      - Loss of Robot: The robot is fully unable to execute the mission. This scenario could be due to technical issues or unfavorable interactions with the competition arena.
   3. In the event a robot experiences a mission-ending anomaly and the team does not voluntarily end the run within a reasonable amount of time, Mission Control and Artemis Arena judges have the authority to terminate the attempt. "Reasonable" is at the judge's discretion based on the specific circumstances of the run. Teams "joyriding" or otherwise wasting competition time may be assessed penalty points.
   4. It is the team's responsibility to ensure they are executing corrective actions efficiently and communicating properly with the MCJ about long cycle steps, such as full system resets, that will make the robot appear further inoperable. Failure to do so could result in the termination of the run.

5. **<u>Mission Conclusion</u>**
   1. Teams must cease operations when the competition timer ends. If the robot is in the middle of an autonomous activity, teams must send a command to inhibit their robot from taking any further actions. Regolith offloading is permitted to be completed if the robot was actively dumping material prior to the expiration of the competition timer.
   2. Teams may not disconnect communications with their robot or begin dismantling their MCC equipment until directed to do so by the MCJ. Sustained operability is necessary in the event the robot must relocate or unload regolith prior to its removal from the Artemis Arena.
   3. Teams should remain in the MCC until dismissed by the MCJ.
   4. Teams are responsible for ensuring they leave the MCC with all equipment they brought into it. Once the next team has entered the MCC, forgotten items cannot be retrieved until that team's run is complete.

2. Autonomous Operations

During each competition attempt, the team will earn up to 500 Construction 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 to make sure their autonomous attempts are recognized and therefore scored correctly. The Caterpillar Autonomy Award will be based on the sum of autonomy scores from both UCF runs and runs at KSC. This means that teams that do not make the top 10 and move to KSC may still be eligible for the Caterpillar Autonomy Awards.

General Rules:

- For clarity, hands-free means that all team members in mission control must be hands-free and not engage any components (e.g. laptops, game controllers, etc.). The team may control the arena camera/s during this time.
- Teams must announce the start and competition of every autonomy point attempt.
- If your autonomy attempt has failed, you must announce your failure before you begin manual control.

Construction points will be awarded for successfully completing the following activities autonomously:

1. Excavation & Dump Automation: 150 pts

1. Teams are allowed to traverse to the Excavation Zone via remote control.
2. Once in the Excavation zone, they must indicate to the MCJ that they are going hands-free for the excavation attempt.
3. The robot must execute machine control commands itself during the excavation task.
4. The robot must demonstrate the ability to excavate, transport, and place. Hands-free operation must begin before the robot engages the regolith to begin the excavation process.
5. Teams must continue in hands-free mode to transport regolith after excavation to the construction zone.
6. The robot must place the regolith at the berm construction location. A discernable amount of regolith must be placed at the berm location as determined by the MCJ. MCJ may engage the arena judges for confirmation if camera angle/performance does not allow confirmation in Mission Control.
7. A complete cycle of digging, transporting, and placing regolith in the berm construction location must be completed in hands-free mode.
8. This level of automation will require teams to master the lower-level machine control of their robot platform associated with excavation and dumping. In addition, teams will need to master localization in the excavation and construction zones as well as path planning to align and place regolith at the designated berm construction location.

2. Excavation & Dump Automation - Full Run: 300 pts

1. Teams are allowed to traverse to the Excavation Zone via remote control.
2. Once in the Excavation zone, they must indicate to the MCJ that they are going hands-free for the excavation attempt.
3. The robot must execute machine control commands itself during the excavation task.
4. The robot must demonstrate the ability to excavate, transport, and place. Hands-free operation must begin before the robot engages the regolith to begin the excavation process.
5. Teams must continue in hands-free mode to transport regolith after excavation to the construction zone.
6. The robot must place the regolith at the berm construction location. A discernable amount of regolith must be placed at the berm location as determined by the MCJ. MCJ may engage the arena judges for confirmation if camera angle/performance does not allow confirmation in Mission Control.
7. The robot must execute a minimum of three excavation, travel, dump, and return to excavation cycles to be eligible for this level of autonomy.
8. The robot must be in hands-free mode at all times in the excavation and construction zones for the entire attempt.
   - A team is allowed to revert to remote control for travel only between the excavation and construction zone one time and will incur a 50-point penalty for remote control.

9. This level of automation will require teams to master the lower-level machine control of their robot platform associated with excavation and dumping. In addition, teams will need to master localization in the excavation and construction zones as well as path planning to align and place regolith at the designated berm construction location. In addition, it will demonstrate the ability to do this over the entire run and adapt to changes in the arena over the course of excavation and dump cycles.

3. Travel Automation: 200 pts

Teams may begin with remote control and move the robot within the starting zone only 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 excavation zone. The robot must start in the starting zone and remain hands-free until any part of the robot has crossed into the excavation zone. This level of automation will require the team to master the following:

1. Localization across the entire competition arena
2. Object detection and location relative to the robot
3. Navigational planning based on location and obstacles/traversable area
4. The competition judges will attempt to construct the obstacle field in such a way as to require obstacle detection, mapping, and navigation planning to determine a "slalom" route to reach the excavation zone. The teams should not architect a "Point and traverse" approach for this automation step.
5. If the robot comes in contact with a rock or drives across a crater in the obstacle zone, as determined by the MCJ/Arena judges, a 35-point reduction will be applied.
6. For maximum points, the attempt must be made at the start of the run when first leaving the starting zone. In order to discourage the approach of "breadcrumbs", a penalty of 50 points will be applied to any attempt that occurs after traversing the obstacle zone in remote control. If multiple attempts are made, this penalty will only be assessed one time to the successful attempt.
7. If attempting excavation and dump automation in coordination with travel automation, the robot must remain in "hands-free" control during travel and excavation.
    - Example: Robot crosses the obstacle course in remote control before the attempt, hits an obstacle, and drives across a crater during the attempt. 200 points – 50 – 35= 115 points.

4. Full Autonomy: 600 pts

1. The robot must be in hands-free control for the entirety of the competition run, completing two or more cycles of excavation and placement at the berm construction location of regolith. Berm construction points, as determined by the volumetric scan, must be achieved for this level of autonomy.
2. If the robot comes in contact with a rock or drives across a crater, as determined by the MCJ/Arena judges, a 35-point reduction will be applied. This is only true in the obstacle zone. The robot is allowed to move rocks and fill in craters in the excavation zone.
3. 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 construction.
    - Example: Robot hits an obstacle and drives across a crater during the attempt. 600 points – 35 = 565 points.

5. Autonomous Operations Scoring

Allowable Combinations	Excavation & Dump	Travel	Excavation & Dump – Full Cycle	Full Autonomy	Total
Ext: 1	150	-	-	-	150
Ext: 2	-	200	-	-	200
Ext: 3	-	-	300	-	300
Ext: 4	150	200	-	-	350
Ext: 5	-	200	300	-	500
Ext: 6	-	-	-	600	600

Autonomous Score Sheet

Any successful completion of the Excavation & Dump and Travel attempts will be combined for scoring. These could occur over separate passes within the run. Excavation & Dump cannot be combined with Excavation & Dump – Full Cycle. Excavation & Dump and/or Travel automation points will not be combined with Full Autonomy.

3. Selected Teams

You are now part of Lunabotics. Congratulations!

1. To remain in the challenge a team shall complete the following:
    1. Complete your student and faculty registration in Gateway and Liability Waiver.
    2. STEM Report
    3. Team Photos
    4. Presentations and Demonstrations (optional but required to be eligible for the Lunabotics Grand Prize, The Artemis Award)
    5. Systems Engineering Paper
    6. Proof of Life Video (this is a pass/fail requirement)
    7. Student / Faculty Registration updated in Gateway to attend the On-Site at KSC.
    8. Please send the List of potential participants (students/faculty) who will be attending UCF and KSC to the Lunabotics mailbox: ksc-lunabotics@mail.nasa.gov
    9. KSC Lunabotics Regulated Waste Management Overview (bring with you to KSC)

2. When you encounter an issue on the NASA Gateway OSTEM application website, send your inquiries to the website Help Desk. Responses to your inquiries may take two or three days. Do not contact Lunabotics about website issues. We do not own the website, cannot unlock your account(s), cannot troubleshoot issues, etc.

3. All email addresses shall use an ".edu" domain address. This applies to the application process as well as communications with Lunabotics. We can only respond to ".edu" email addresses.

4. The timeline/deadlines for all Lunabotics items is posted on the Lunabotics Website. STEM Gateway application site opens seven (7) days prior to a deadline (milestone). Deadlines are at 5:00 PM Eastern Time. Dates Are Subject to Change. See https://www.nasa.gov/learning-resources/lunabotics-challenge/timeline/

5. You cannot "delete" a file from the Gateway system; you can only add files. Lunabotics will review the most recent file that was received prior to the deadline. NASA reserves the right to question or reject any item if submitted by a party not authorized to represent the institution in question.

6. The team lead will be responsible for uploading the deliverables to the STEM Gateway Website. The following deliverables are required to continue in the Lunabotics competition. Use the following format to name your PDF files, Deliverable Name-School Name (not your team's name)]:

    1. Liability Waiver
    2. Waiver-School Name

    3. STEM Report
    4. STEM-School Name

    5. Team Photos and NASA Media Release
    6. Photo-School Name

    7. Presentations and Demonstrations
    8. PD-School Name

    9. Systems Engineering Paper
    10. SEP-School Name

    11. Proof of Life Video
    12. POL-School Name

    13. Student/Faculty Registration updated in Gateway to attend the On-Site at KSC.

    14. Send a List of potential participants (students/faculty) who will be attending UCF and KSC to the Lunabotics mailbox: ksc-lunabotics@mail.nasa.gov

    15. KSC Lunabotics Regulated Waste Management Overview (bring a hard copy with you to KSC).

SECTION 3: DELIVERABLES AND RUBRICS

If it is evident to the Lunabotics judges the team has not fulfilled the spirit and intent of the deliverable, then a score of zero shall be assigned and the team shall be removed from the challenge.

The team lead will be the responsible party to upload the deliverable to the STEM Gateway Website. The following deliverables are required to remain in the Lunabotics Challenge [use the following format to name your PDF files, Deliverable Name-School Name (NOT YOUR TEAM'S NAME)]:

1. Project Management Plan (PMP)

Resources available:

1. A video series introducing the key project management and systems engineering products and how to apply them to your project can be viewed at Systems Engineering for University-level Engineering Projects and Competitions | NASA
2. A video of the Project Management and Systems Engineering Seminar presented at the 2022 Lunabotics competition at KSC can be viewed Here.
3. A video of the Seminar presented at the 2024 Lunabotics competition at UCF titled "How to Develop the Perfect Lunabotics SE Paper" can be viewed Here.
4. A video of the Seminar presented at the 2024 Lunabotics competition at UCF titled "System's 'd'esign" can be viewed Here.

Each team shall submit a complete Project Management Plan (PMP) electronically in one PDF file. 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.

Include your school name on the PMP.

Maximum length of the plan is 5 pages. If you include a cover page, it will not count towards the page limit. Any content over 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.

Here are some Tips on the PMP previously provided:

Project Management Plan (PMP) Tip #1: Make sure your Gantt Chart (if using) and tables are readable if you are providing them to satisfy a rubric element. If we can't read it, we can't give you points. If you provide graphics with unreadable (less than 9-point text as viewed in the pdf) text, make sure the information to satisfy the rubric elements are discussed in the main body (at least 12 point font).

Project Management Plan (PMP) Tip #2: Initial Project Schedule: Major Reviews. Make sure at least 3 show up on your schedule: SRR, PDR, and CDR. If you are using an alternate review instead of SRR, PDR, and CDR, then identify the name of the review that replaces each in the discussion.

Project Management Plan (PMP) Tip #3: Developing any management plan boils down to two things: making decisions and writing them down. It's important to document those decisions at the beginning of the project and share with your team. Update your plan as you learn more and your project progresses. The Project Management Plan rubric identifies an important subset of the decisions you will have to make in your Lunabotics project planning process, and asks you to tell us what those specific decisions were.

Project Management Plan (PMP) Tip #4: Initial Project Budget: Budget evolution. As your design matures, you will learn more about how much your project is to actually going to end up costing. To be sure you don't run out of money before the end of the project, set up periodic reviews of your cost budget. If your costs are much greater (or much less) than you expect, decide at the beginning of the project how you will address budget shortfalls, and what you will do with budget excesses. Don't forget to make these decisions and discuss them in your PMP.

Project Management Plan (PMP) Tip #5: Initial Technical Performance Measures (TPM): Allocation to System Hierarchy. The system hierarchy is the backbone of your project. At the very start of a project, it may only consist of two levels. That early decomposition allows you to allocate how much time you plan to spend on each sub-element in the hierarchy, how much money you plan to spend on each sub-element, and how much of the technical performance measure's values each sub-element will have to provide so the system can accomplish the mission. As your design matures, these early allocations of TPM values across the system hierarchy levels will guide you through the design process to deeper levels in the system hierarchy, and enable sub-allocations of TPM values across these new levels. And of course, you may learn things in the design process that might change even those earliest allocations of TPM values. There is an example of allocations down through the system hierarchy in SE Video 2: 'The Central Elements of Project Management'. That video describes budget allocation; the approach is similar for mass and other TPM allocations. Don't forget to include the TPM allocations in your PMP.

SCORING RUBRIC – PROJECT MANAGEMENT PLAN

Element	Points
Initial Project Schedule Provide a Gantt Chart or equivalent that shows the project's major due dates and events to include at least the five items listed below. Discuss these only as needed. 1. Start Date 2. Completion Date: (after project decommissioning; this is the date when you have disposed of your robot system after the challenge; for example, you hand the system over to next year's team, dispose of it or other) 3. Dates for the 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. Product delivery dates to the Lunabotics Engineering Challenge, including as a minimum ✪ delivery of Systems Engineering Paper, ✪ the planned date to submit "Proof of Life" 5. Dates for 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).	**There are 3 points total for 6 elements**

SCORING RUBRIC – PROJECT MANAGEMENT PLAN

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Initial Project Cost Budget

Provide an estimate of the total project cost, inclusive of all possible costs. Provide a Table of Major Budget Categories and Items including the following list items as a minimum. Discuss only as needed.

1. Breakdown of total project cost estimate for at least the following major items. (Total should add up to the estimate of the total project cost.)
    - ✪ Cost estimates for elements in the earliest level System Hierarchy (provide this earliest level System Hierarchy, which may only be two levels at this early point in the project). Break these estimates down as follows.
        - ❖ Labor costs, if any
        - ❖ Material costs for challenge (for production and completion of Lunabotics deliverables)
    - ✪ Travel costs including costs to travel to UCF and KSC if you intend to accept a proffered invitation to UCF to participate in UCF's Lunabotics Qualification Challenge and to KSC to participate in NASA's Lunabotics On-Site Challenge

Identify any Critical scheduling milestones (and dates) for budget or cost related items. (These critical cost budget milestones should appear in item 5 for the Initial Project Schedule; for example, dates funds will be needed, planned activities to raise funds, or others).

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).

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There are 3 points total for 3 elements

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Project Technical Objectives

List and discuss the specific technical criteria or characteristics that your team intends to achieve (typically some technical parameter or measure you want to minimize or maximize, increase to some limit, or decrease to some limit) in your system design and operations to win the competition. These provide the technical direction and focus for the entire team in design and operations. For example: you might choose to minimize mass, or maximize automation, or minimize bandwidth, or some combination of these (or any other criteria or combination of criteria) to produce a system that will win the competition.

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There is 1 point total for 1 element

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SCORING RUBRIC – PROJECT MANAGEMENT PLAN

Element	Points
Initial Technical Performance Measures (Technical Budgets) Provide a Table of Technical Performance Measures that you deem are important for your design to accomplish the mission. A Technical Performance Measure is any quantifiable technical characteristic that you may consider important, difficult to achieve, or particularly risky to project success, and may derive from your Project Technical Objectives. For example, it may be that total mass (high or low) is important to you, or that a low bandwidth is difficult to achieve, or that high speed is risky for your project, or any number of other quantifiable and measurable technical quantities. Include the following in the table as a minimum. Discuss only as needed. 1. Identification of Technical Performance Measures 2. Initial Target Value for each Technical Performance Measure to be achieved by the challenge Provide the allocation of each Initial Target Technical Performance Measure value across the elements of the earliest System Hierarchy (should combine to the total at the highest level). Discuss any critical schedule milestones (and dates) 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.) 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 Performance Measure values, and how you plan to adapt to performance shortfalls or exceedances should they occur).	**There is 1 point total for 1 element**

2. STEM Engagement Report Rubric)

Each team must participate in engagement activities with at least one Elementary, Middle, or High School (K-12) student group in their local community and submit a report detailing their engagements. This project is designed to engage K–12 students in STEM (Science, Technology, Engineering, and Math) through direct (hands-on) and indirect activities. Teams must include data regarding the students reached with the engagement activities. We suggest using a table like the one shown below. We encourage teams to engage with underrepresented and underserved local community students.

Activity Date	Activity	Outreach Recipient Group	K–3rd grand level participants	3rd–5th grade level participants	6–8th grade level participants	9–12th grade level participants
9/24/2024	Presentation about the Moon	Wissahickon Elementary School	5	5	0	0
9/24/2024	Hands on Moon Dust Activity	Wissahickon Elementary School	5	5	0	0

Teams will also be required to include a table recording the total hours dedicated to the engagement activities by each team member in their report.

The Engagement activities must include at least one Indirect Educational Engagement and one Direct Educational Engagement. Definitions and examples of Indirect and Direct Educational Engagements are outlined below. **Please read carefully, as this section has been updated from last year.**

Indirect Educational Engagement (Student-centered)

The report must include at least one Indirect Educational Engagement centered around the Lunar surface or robotics. This Activity should connect to what you teach the K–12 Students in Direct Engagement. The teacher facilitates the activity without direct instruction.

Indirect Educational Engagement is instructional, hands-on activities where participants engage in learning a STEM-related concept by actively participating in an activity. This includes instructor-led facilitation or inquiry around an activity regardless of media (e.g., face-to-face, video, conference, etc.).

> **Example:** Students learn about lunar robotics by creating their own robotics experiment with the help of the team to go on an Artemis-themed "mission," such as collecting resources, constructing a base, or surveying craters.

Direct Educational Engagement (Teacher-led)

The report must include at least one Direct Educational Engagement focused on teaching the K–12 Students about the Lunabotics team's robot or the moon. This engagement should give context for the indirect activity and connect it to NASA and/or the Artemis Mission.

Direct Educational Engagement is when participants are engaged in learning a STEM concept through instructor-led facilitation or presentation.

> **Example:** Students learn about why lunar regolith presents design challenges for robotics/space systems through a presentation or lecture.

The activities may be conducted at the same event and with the same student group, but both must be completed by the submission deadline. Additional completed engagement activities may be included in the body of the report but are not required. Plans for future engagement may be included in the appendix (not body of the report) but are not required.

The Appendix has a 5-page limit, totaling a 10-page maximum (not including Cover Page or any references). If photographs make your appendix too large, consider sharing them as a link to a cloud folder containing the photographs to save space. More information about the 5E model of instruction will be made available through a STEM Engagement Report Webinar, which will be held in the fall.

The STEM Engagement Report will be judged according to the following rubric. If there is a tie, the winner will be chosen at the judges' discretion.

Element	Points
Structure, Content, and Formatting Section	
• Maximum of 5-page body. • Maximum 5-page appendix. • Cover page (not included in page count) must include team name, title of paper, full names of all team members, university name, and faculty advisor's full name. • The cover page must also include the faculty's signature and a statement that they have read and reviewed the paper prior to submission. • Formatted professionally, clearly organized, correct grammar, and spelling, size 12 font, single spaced.	1 point
The appendix includes a write up of the team's engagement activities using the 5E model of instruction.	1 point
Pictures or video clips must appropriately demonstrate the activities (provide a link in the document or include images in the report body or appendix).	1 point
The report must include a table describing how the Lunabotics Competition team participated, the number of team members present, and the number of hours each team member contributed.	1 point
The report identifies lessons learned and plans for improvement.	1 point
The report describes student outcomes and accomplishments. What did they learn? Provide evidence.	1 point
The report must show statistics on the participants and activities.	1 point
Structure, Content, and Formatting Section Subtotal	**7 points**
Indirect Educational Engagement Section	
The report describes a hands-on activity that teaches K–12 students about the moon or robotics.	1 point
The report identifies the materials used and the rationale behind these decisions (cost, user-friendliness, access, etc.).	1 point
The report identifies the level of familiarity students had with the activity topic pre and post activity. What new things did they learn?	1 point

Element	Points
The team makes connections to other uses for the skills the K–12 students learn in their indirect engagement. How could the younger students apply what they learned to something else?	1 point
Indirect Educational Engagement Section Subtotal	**4 points**
Direct Education Engagement Section	
The report describes a direct educational engagement that educated K–12 students about their robot or the moon.	1 point
The Report identifies how the team members shared their STEM journey with the K–12 Students. How did you get to a Lunabotics Team, and what do you do now?	1 point
The Report describes how the team inspired the K–12 students to get involved in STEM or STEM careers	1 point
The report describes how the team shared their robot with the K–12 students. What specifically did you teach them about your robot?	1 point
Direct Education Engagement Section Subtotal	**4 points**
Grand Total of Points	**15 points**

NASA Educator Resources

The following new resources contain hands-on Moon activities and videos that NASA has developed for the Artemis Mission that can be used for the STEM Engagement Report.

- Landing Humans on the Moon Educator Guide (nasa.gov) – This educator guide contains activities and pictures for your presentations and rubrics for the Engineering Design Process and Scientific Process. Activities and topics included are:
  - ➤ water filtration
  - ➤ lunar surface activities
  - ➤ choosing a landing site on the moon
  - ➤ sculpting lunar geology
  - ➤ priority packing
  - ➤ safe landing on the lunar surface
- ‘First Woman’ Graphic Novel and Camp Experience – The novel is available in English and Spanish. The Camp experience includes hands-on activities that are excellent examples of Moon-based STEM engagement activities. Activities and topics covered are:
  - ➤ The “Artemis” Mission
  - ➤ Electrostatic Moon Duster activity
  - ➤ Digging on the Moon activity
  - ➤ Printing a Lunar Habitat
  - ➤ Finding our Way on the Moon (robotic)

Student Activity Videos

These short videos introduce the hands-on activities for the First Woman Camp Experience.

- NASA's Deep Space Communications Game Instructions
- RoboTools Engineering Design Challenge
- Design a Spacecraft Drag System like NASA
- Filling Up in Space: NASA Engineering Design Challenge
- Digging on the Moon

Artemis-Related / Space Tire Engineer Videos

- Why the Moon? - Explains why returning to the Moon is the natural next step in human exploration and how the lessons learned from Artemis will pave the way to Mars. https://youtu.be/bmC-FwibsZg
- Artemis I mission highlights video – This is a short recap of our first step on the path back to the Moon. https://youtu.be/jrDv0OdMt5s
- Artemis II Crewed Mission Overview – Provides a short overview of the first crew test flight. https://www.nasa.gov/artemis/videos.
- Artemis II Meet the Astronauts Who will Fly Around the Moon (Official NASA Video).mp4
- Surprisingly STEM Space Tire Engineer video – Watch a NASA Engineer discuss her career path to developing tires for robots going to the Moon. https://plus.nasa.gov/video/surprisingly-stem-space-tire-engineer-2/
- Explore NASA's Electrostatic Moon Duster Activity – Use the first part of the video to help K-12 students understand the difficulties dust poses to operations on the Moon back in the Apollo era and for future Artemis missions.

Robotic Activities – Mars

STEM Lessons for Educators – NASA Jet Propulsion Laboratory

These lessons are from the NASA Jet Propulsion Laboratory with robotic activities for Mars. While these activities are Mars-based, university teams can modify the activity to make it Moon-themed. Activities covered are:

- Designing a Robotic Insect
- Robotics: Making a Self-Driving Robot
- Robotics: Creating a Roving Science Lab
- Robotic Arm Challenge

3. Presentation and Demonstration (P&D) Rubric

Teams must participate in this event to qualify for the Lunabotics grand prize. It is otherwise optional, and teams will not be penalized for choosing not to participate.

Competing teams shall deliver a completed Presentation and Demonstration slideshow in one PDF file in accordance with Lunabotics submission guidelines. Teams are not permitted to modify their slides between submission to NASA and presentation to the P&D Judges Panel. Penalty points may be assessed for non-compliance. If a Team has updated progress they want to share with the judges, they may verbally address it in the appropriate section of their presentation.

1. P&D will occur virtually prior to the UCF Qualifiers. NASA will establish the judging schedule after the presentation deadline closes and allow teams to select their time slots on a first-come, first-served basis. NASA will provide the virtual meeting location and include setup time in each slot prior to the judging panel's arrival. Teams that submit slides but do not present will not receive a score for this event.

2. Each team is allotted 25 minutes before the judging panel and should be prepared to present their own slides. The presentation and demonstration are expected to last approximately 20 minutes, with the final 5 minutes available for questions and answers. To maintain the judging schedule, there is a hard cut-off at the 25-minute mark. Teams are responsible for managing their time accordingly.

3. A panel of engineering professionals will judge the presentations on content coverage, team performance, and overall slide quality (e.g., grammar and spelling, use of graphics, general aesthetics). Chart packages must be logically organized with proper supporting slides to augment the scored content. Teams should remember they are representing their university as well as their work for the competition and should strive to do so in a manner befitting both.

4. While a live demonstration of all functions via the control system is preferred, the judges recognize that it is not always possible. If parts or the entire robot cannot be controlled at the time of the demonstration, it is acceptable to move parts by hand (if the robot is powered off), show video from practice runs, etc., to communicate the functionality and attributes of the system and/or subsystems.

5. Each team must provide a safety plan immediately prior to their demonstration. Teams unable to perform a live demonstration are not exempt from this requirement. They are expected to identify safety considerations relevant to what they will demonstrate or, in the case of videos, what safety practices they follow.

6. Teams who do not present an acceptable safety plan to the judging panel will not be allowed to demonstrate. Teams who fail to adhere to their safety plan may have their demonstration cut short. In both cases, teams will receive a score of zero for the demonstration portion of the rubric.

SCORING RUBRIC – PRESENTATION AND DEMONSTRATION

Element	Points
Scoring Element 1: Content Coverage 1. Project Objectives: Qualitative technical objectives and quantitative Technical Performance Measures 2. Design Process: Systems Engineering approach and execution 3. Project Management: Budget and schedule evolution, team management, risk mitigation 4. Concept Development: System trades, reuse decisions, and planned configuration 5. Design Maturation: Subsystem trades, reuse decisions, and final configuration (mechanical, electrical, and software) 6. System Testing: Test plan, test progress, test results relative to project objectives, etc. 7. Safety: Considerations in design, development, and test; implemented safety features, etc.	**There are 15 points for this element.**
Scoring Element 2: Presentation Execution 1. Slide Quality: Organization, grammar and spelling, formatting, graphics usage, general aesthetics, etc. 2. Preparedness: Team cohesion, time management, proper consideration of the virtual format (e.g., slide visibility, audio quality, participant mic/camera awareness), sufficient mitigation of external distractions and technical issues, etc. 3. Delivery: Presenter body language, cadence, enthusiasm, comfort with the material, communication effectiveness, camera awareness, etc. 4. Question and Answer Session: Demonstrated understanding of questions and quality of responses	**There are 5 points for this element.**
Scoring Element 3: Demonstration *Reminder: Teams who do not present an acceptable safety plan to the judging panel will not be allowed to demonstrate. Teams who fail to adhere to their safety plan may have their demonstration cut short. In both cases, teams will receive a score of zero for the demonstration portion of the rubric.* 1. Demonstration Safety Plan: Safety plan is clearly communicated, suitable for the type of demonstration to be performed, and followed. 2. Preparedness: Organization and flow, consideration of the virtual format (e.g., suitability of demo location, robot visibility, presenter audio quality, participant mic/camera awareness), explanation quality, time management, etc. 3. Scope: Systems demonstrated and their associated depth of coverage	**There are 5 points for this element.**

4. Systems Engineering Paper Rubric

Resources available:

1. A video series introducing the key products and techniques of systems engineering and how to apply them to your project can be viewed Here.
2. A video of the Project Management and Systems Engineering Seminar presented at the Lunabotics competition at KSC can be viewed Here.
3. A video of the Seminar "How to Develop the Perfect Lunabotics SE Paper" presented at the 2024 Lunabotics competition at UCF can be viewed Here.
4. A video of the Seminar presented at the 2024 Lunabotics competition at UCF titled "System's 'd'esign" can be viewed Here.
5. *As one example, undergraduate course materials in systems engineering are available* Here.

Directions:

1. Each team shall submit a complete Systems Engineering Paper electronically in one PDF file.
2. 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.
3. 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.
4. Either one-column or two-column formatting is acceptable. The "professional journal margins" note reminds authors to provide appropriate white space at the margins and between sections.

SCORING RUBRIC – SYSTEMS ENGINEERING PAPER

Element	Points
Content 1. Format: **Provide a cover page.** The cover page shall include team name, title of paper, full names of all team members, university name, and faculty advisor's full name. The Systems Engineering Paper shall consist of a maximum of 25 pages not including the cover page, title page, table of contents, and a list of references pages. If a team chooses to use appendices, they shall be within the 25-page count. Content in the appendices shall be addressed in the main body of the paper. ***Only the first 25 pages of the paper will be judged.*** 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 • Correct grammar and spelling • 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 and single spaced 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.	**There are 3 points for 3 elements, one point each**

<table>
<tr><th>Element</th><th>Points</th></tr>
<tr><td>
3. <u>Reason for using Systems Engineering:</u>
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.)
</td><td></td></tr>
<tr><td>
Project Management Merit

1. <u>Is your system a New Design or Design Update?</u>

The Lunabotics System Engineering Paper should only describe the systems engineering done during this competition year. If your system design is a new clean-sheet-of-paper design, then by default the paper would address the systems engineering you did to develop all of this new design, implement it, and field it for the competition.

If your system design this year is a substantial modification of some previous system, the only systems engineering you should address this year is on development of the modified or added system hierarchy elements (subsystems/assemblies/components), how you interfaced the modified or added hierarchy elements with the previous system's hierarchy elements, and how you verified that the key driving requirements are satisfied in the modified system.

Provide the following:

Clearly state that the system is an entirely new system design, or that it is a substantial update to a design from a previous competition (minor tweaks to a previous design will not allow sufficient exercise of Systems Engineering practices to allow SE Paper scoring).
If you have a substantially updated design, specifically address the following:

Provide the system hierarchy for the previous system and clearly identify on it which hierarchy elements were changed or added/deleted for this year's competition; and,
Explain how you arrived at your decisions to change (or add/delete) these hierarchy elements.

If you have an entirely new system design, only content specifically relative to that new system design in the SE Paper will be subject to judging. Any references to systems engineering performed on previous designs, and any discussions of previous designs, will not contribute to scoring any rubric elements in the paper.
If you have a substantially updated design, any content in the paper that addresses the previous system will not contribute to scoring, except how the modified system hierarchy elements interface with the previous system hierarchy elements and how the modified system is verified to satisfy its key driving requirements.

[3 points]

2. <u>Major Reviews:</u>

At a minimum, describe how you conducted the System Requirements Review (SRR), Preliminary Design Review (PDR), and Critical Design Review (CDR)

Clearly demonstrate that these reviews served as control gates.

Identify the external reviewers, and their comments which led to changes in the system design (requirements), the schedule, the cost budget, and/or TPM's.
</td><td>
8 points for 4 elements.

2 bonus points may be awarded for exceptional work on Project Management Merit elements
</td></tr>
</table>

Element	Points
Provide examples of changes that occurred specifically as the result of external reviewers' comments at each review to: • The system design (provide examples of requirements before the comments and the changed requirements as a result of the comments). • The schedule. • The cost budget. • Technical Performance Measurements values or allocation of values across a system hierarchy level. *[3 points]* 3. <u>Schedule of work:</u> Discuss the project schedule and how it evolved from inception to disposal of robot system. Provide the original planned schedule before project start (the one you submitted as part of the PMP). Provide as a minimum the actual final schedule (or schedule at the time the paper is delivered). You may provide other interim schedules at relevant milestones as well. Provide examples of: • What changed between the original and subsequent schedules. • Why it changed. • When it changed. • How these changes affected the cost budget and relevant technical requirements (i.e., requirements before the schedule change and the changed requirements as a result of the schedule change). 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. [1 point] 4. <u>Cost budget:</u> Discuss the cost budget for total project costs (including travel, especially the travel costs if you intend to accept an invitation to UCF to participate in UCF's Lunabotics Qualification Challenge and to KSC to participate in NASA's Lunabotics On-Site Challenge if proffered) and how it evolved from inception to disposal of robot system. Provide the original total estimated project cost and budget before project start, and as a minimum the actual final project cost and budget (or at the time the paper is delivered). You may provide other interim cost budgets at relevant milestones as well.	

Element	Points
Provide examples of: • What changed between the provided cost budgets. • Why it changed. • When it changed. • How these changes affected the schedule and relevant technical requirements (i.e., requirements before the schedule change and the changed requirements as a result of the schedule change). 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. *[1 point]*	
Systems Engineering Merit 1. <u>System Hierarchy:</u> Provide top-down breakdowns of the system design at each control gate or major review (SRR, PDR, CDR). If you have a substantially updated system design this year, indicate clearly for all Systems Engineering Merit elements in the paper which hierarchy elements are from the previous design, and which are modified or new. 2. <u>Requirements</u>: Identify the key driving requirements for robot system design, operations, interfaces, testing, safety, reliability, etc., stated in proper "shall" language. (Key driving requirements will include system and lower-level derived requirements.) Each of these requirements should specifically be addressed when you discuss verification – see Systems Engineering Merit element 8 "Verification of system meeting requirements." 3. <u>Interfaces:</u> Identify the key important interfaces between elements in the system hierarchy at each system hierarchy level. Identify the type (e.g., mechanical, electrical, human, signal, data, communication, etc.) of each key important interface. Identify which key important interfaces are interfaces to elements external to the system. Demonstrate how consideration of the interfaces affected system design. Indicate which of the key driving requirements are interface requirements. 4. <u>Engineering Specialties:</u> Identify the engineering specialties that you deem important in your system for accomplishing the mission. Discuss how considerations of these engineering specialties affected design and operations. Identify key driving requirements for design and operations that resulted from the considerations of these specialties in the design process. Indicate which of these engineering specialties played a role as evaluation criteria in trade studies. The following are examples of a few engineering specialties that may or may not be important for your system design. There may be several others not listed here that you deem important to your system. Only discuss those that you deem important to your system. • **Reliability** (what did you have to design into your system to assure that the system will operate properly until the end of the competition)	**8 points for 8 elements, one for each element.** **Up to 4 additional points for exceptional work and additional systems engineering methods used.**

Element	Points
Maintainability (what did you have to design into your system to assure that you can maintain and repair your system if it fails at the competition, and what tools you might need for repairs and maintenance), **Logistics** (what did you have to design into your system to assure that if you have a failure at the competition that you have on hand parts for repairs and maintenance, possibly bringing spare parts with you or finding parts sources local to the competition), **Transportability** (what did you have to design into your system to be able to transport your system to and from the competition in a working condition, including possibly design features and tools needed for easy disassembly for packing/transport/shipping and reassembly at the competition), **Safety** (what did you have to design into your system to assure that it cannot cause injury or damage during the mission from pack up to leave until return home and disposal)]. 5. <u>Concept of Operations (ConOps):</u> Describe how the team will operate the elements of the system hierarchy, at each system hierarchy level, under the environmental conditions of the competition, to accomplish the robot system mission. Indicate which of the key driving requirements are operations requirements. 6. <u>Technical Performance Measurement:</u> Identify and discuss technical measures that you deem to be important to accomplishing the mission and that you used to manage the project. A Technical Performance Measure is any quantifiable and measurable technical characteristic that you may consider important, difficult to achieve, or particularly risky to project success, and may derive from your Project Technical Objectives. For example, it may be that total mass (high or low) is important to you, or that a low bandwidth is difficult to achieve, or that high speed is risky for your project, or any number of other quantifiable and measurable technical quantities. Provide the allocation of TPM values to elements of the system hierarchy across each level of the system hierarchy. Discuss how that allocation of TPM values changed as the system design evolves through final verification. Demonstrate that the budgeting and management of these important technical quantities was used in management of the design process. 7. <u>Trade Studies:</u> Discuss how important system decisions were made using trade studies, i.e., using weighted evaluation criteria scorings of alternatives. Indicate which of the key driving requirements resulted from trade studies. (The result of any decision important enough to need a trade should by definition be captured as a key driving requirement.) 8. <u>Verification of system meeting requirements:</u> Discuss how you assured 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, each of the key driving requirements that you identified in the section addressing Systems Engineering Merit element 2 “Requirements.” Provide the success criterion for each verification. Discuss how the key important interfaces were verified or are planned to be verified in the system build processes.	

5. Proof of Life (PoL) Video and Robot Data

There are no points for this, but these are required deliverables, and failure to submit them will result in disqualification from the challenge.

Proof of Life

A video recording of the faculty advisor verifying the following:

- The robot being weighed – on a scale.
- The dimensions being verified – using a measuring tape.
- Routers are required to be able to turn off the 2.4 GHz band.
- The video shall be of one complete cycle of operations or 15 minutes of continuous operations.

Your operations area can use the beach, play, construction, or outdoor volleyball sand as an acceptable granular material. If weather or other issues prevent operations on a granular surface, use your best judgment to record operations.

Submit a YouTube link to your video recording. Present what you can by the due date. The spirit and intent are that you have a functioning robot to present to the NASA judging staff.

ROBOT DATA

The purpose of this form is to collect data about your team's robot. One for each robot.

Information on this deliverable will be provided prior to the on-site events.

Summary of Deliverables

Applying to the Lunabotics Challenge

Statement of Support
SOS-School Name

Statement of Rights of Use
SRU-School Name

Project Management Plan
PMP-School Name

Selected Teams to be in the Lunabotics Challenge

Team Photos and NASA Media Release for Adults (Do Not Use for Minors) for each photo submitted
Photos-School Name

STEM Engagement Report
STEM-School Name

Presentation and Demonstration Slides
PD-School Name

Systems Engineering Paper
SEP-School Name

Proof of Life Video and Robot Survey (the POL is a pass / fail item)
POL-School Name

Selected Teams to attend the On-Site Qualification Challenge at UCF

Student / Faculty Registration to Attend Lunabotics Week (send to ksc-lunabotics@mail.nasa.gov)

Selected Teams to attend the On-Site Finals at KSC

KSC Lunabotics Regulated Waste Management Overview
RWMO-School Name

Liability Waiver Artemis Arena
LIA-School Name

KSC REGULATED WASTE MANAGEMENT OVERVIEW

Students and faculty advisors attending the on-site must read the following and sign the document at the end of this section and submit on the NASA Gateway OSTEM Application Website.

NASA Environmental Protection Specialist Environmental Assurance Branch (SI-E2)
This is not formal/official RCRA training. This is a basic overview of KSC waste management policy.

TOPICS

KSC Hazardous Waste Subject Matter Expert
Background and Regulatory Requirements
Examples of Waste
Waste Site and Locations
Waste Generators

KSC Hazardous Waste Subject Matter Expert – **Al Gibson**

- Will be in the pit area throughout the event
- Visiting each team
- If you have a question or concern, please contact:
  - albert.e.gibson@nasa.gov
  - 321-861-0863

Background & Regulatory Requirements

- Hazardous Waste Laws, Regulations, & Agencies
  - Federal Law: Resource Conservation & Recovery Act (RCRA)
  - Regulations: Code of Federal Regulations, Title 40, Parts 240- 299 United States Environmental Protection Agency (EPA)
  - Regulations: Florida Administrative Code Chapter 62-730 Florida Department of Environmental Protection (FDEP)
  - EPA delegated its authority to enforce RCRA regulations to FDEP
  - FDEP performs inspections, permitting, & enforcement at KSC
- Hazardous Waste Types
  - Characteristic (flammable, corrosive, toxic, or reactive)
  - Listed (from a specific source)
- Hazardous Waste Violations
  - In 2021, Florida's hazardous waste program completed 34 formal enforcement actions (consent orders) for a total of $821,851.75 in civil penalties.
  - Criminal penalties – fines and/or jail time
- KSC "Large Quantity Generator" of Hazardous Waste
  - Stricter management and reporting requirements and must comply with 40 CFR 262.15 and 40 CFR 262.17
- Increased oversight by regulatory agencies
- Hazardous Waste Cradle-to-Grave Liability
  - Listed EPA Waste
  - Hazardous waste sites are either Satellite Accumulation Area (SAA) or Central Accumulation Area (CAA)
- Controlled Waste
  - Non-hazardous wastes not regulated by other laws i.e., used oil dry.
- Universal Waste
  - Certain wastes that are exempt from being managed as hazardous waste as long as they are recycled, reused, or reclaimed in a certain manner.
  - If not managed as universal waste, it falls under the hazardous waste rules

Examples of Waste

- Hazardous Waste Examples
  - PVC primer, cleaner and cement
  - Hypergolic scrubber liquor
  - Spent isopropyl alcohol & cleaning solvents
  - Solvent wipes
  - Paint thinners & unused paint

- Acetone
- Super glue

➤ Examples of Controlled Waste
- Used oil & oily wipes
- Petroleum contaminated material

➤ Examples of Universal Waste
- Aerosol cans
- Batteries

Waste Site and Locations

➤ There will be a SAA waste site in the “Pit Area” and one in the “Bot Shop”.
➤ Place your waste in the appropriate container. If you are not sure, see the Pit Boss.

Waste Generators

Lunabotics waste generators training requirements are to:
- Know hazardous waste has been generated (hazardous material = hazardous waste)
- Know the waste must be managed in accordance with the RCRA regulations (i.e., ensure proper handling, it does not go in the trash or poured/flushed into the sewer.)
- If you are not sure about your waste let the Pit Boss know.

If you see an issue report it to the Pit Boss.

Always follow proper safety protocol and use material as defined by the manufacture.

If you don’t know the KSC way, ask – we are here to help you.

Acknowledgement

Signature Sheet for Faculty Advisor and Students Attending. By signing this sheet, you affirm you have read this document.You will abide by KSC policy and procures for handling hazardous waste while attending Lunabotics.

Any questions or concerns about KSC Hazardous & Controlled Waste Management should be address to Al Gibson, albert.e.gibson@nasa.gov, 321-861-086

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NASA Media Release for Adults
(Do Not Use for Minors)

I, ____ do hereby give permission to be
(Please print name your name)

interviewed, photographed, and/or videotaped by NASA or its representatives in connection with a NASA production.

I understand and agree that the text, photographs, and/or videotapes thereof containing my name, likeness, and voice, including transcripts thereof, may be used in the production of instructional, promotional materials, and for other purposes that NASA deems appropriate and that such materials may be distributed to the public and displayed publicly one or more times and in different formats, including but not limited to, websites, cablecasting, broadcasting, and other forms of transmission to the public. I also understand that this permission to use the text, photographs, videotapes, and name in such material is not limited in time and that I will not receive any compensation for granting this permission.

I understand that NASA has no obligation to use my name, likeness, or voice in the materials it produces, but if NASA so decides to use them, I acknowledge that it may edit such materials. I hereby waive the right to inspect or approve any such use, either in advance or following distribution or display.

I hereby unconditionally release NASA and its representatives from any and all claims and demands arising out of the activities authorized under the terms of this agreement.

By signing below, I represent that I am of legal age, have full legal capacity, and agree that I will not revoke or deny this agreement at any time.

I have read the foregoing and fully understand its contents.

Accepted by:

Signature:____ Date: ________________

Name and Location of Event: ____

Address: ____

Telephone: ____

Email Address:____

WAIVER OF LIABILITY AND HOLD HARMLESS AGREEMENT FOR ACCESS TO THE ARTEMIS ARENA

1. In consideration of the permission granted by the National Aeronautics and Space Administration (NASA), Kennedy Space Center (KSC), to enter the Artemis Arena, I hereby release NASA, KSC, their officers and personnel, agents, servants, employees, representatives, successors, assigns, (hereinafter referred to as RELEASEES), from liability for any loss, damage, injury, or death, that may be sustained by me, or any of the property belonging to me, while participating in such activity and caused or alleged to be caused in whole or in part by the negligence of the RELEASEES. I have been informed of all the activities in which I will engage as a participant in the Artemis Arena and understand that these activities carry risk of injury, death, and property damage.

2. I also waive all claims, demands, damages, actions and suits against the United States of America and RELEASEES, arising out of or related to any loss, damage, injury, or death, that may be sustained by me, or any of the property belonging to me, while participating in such activity, or that occurs incident to my entering in, on, or upon KSC premises.

3. I am fully aware of the risks involved and the hazards connected with activities associated with the Artemis Arena, and I am fully aware that there may be risks and hazards unknown to me connected with being on the premises and participating such activities, and I hereby elect to voluntarily participate in said activities with full knowledge that said activities may be hazardous to me and my property. I voluntarily assume full responsibility for any risks of loss, property damage, personal injury, or death, which I may sustain as a result of engaging in such activities.

4. It is my express intent that this Waiver of Liability and Hold Harmless Agreement shall bind the members of my family and spouse, if I am alive, and my heirs, assigns, executors, administrators and personal representative, if I am deceased. In addition, I agree to abide by all safety and security regulations of NASA KSC and the State of Florida. I agree to comply with all directions from security and safety personnel.

5. I certify that I have not been advised against participation in these types of activities by a health professional and that I am physically able to participate in this type of activity. I hereby authorize emergency medical treatment in the event of injury or illness. I also authorize trained health care providers to administer routine and/or emergency medicines and treatments, as needed.

6. In signing this release, I acknowledge and represent that I have read the foregoing Waiver of Liability and Hold Harmless Agreement, that I understand it and that I sign it voluntarily as my own free act and deed. I execute this Release for full, adequate and complete consideration fully intending to be bound by same.

Signed on this ______ day of ____________________________ , 20 ____ .

______________________________	______________________________
Participant's Name (printed)	Participant's Signature

If Participant named above is under the age of 18, I, as Participant's Parent/Guardian consent to the minor's participation in the event, give consent for NASA KSC to seek reasonable and necessary medical treatment for Participant during such event or associated activities, and agree to be responsible for any cost of such treatment.

______________________________	______________________________
Parent/Guardian Signature	Date

WAVIER OF LIABILITY AND HOLD HARMLESS AGREEMENT FOR ACCESS TO THE ARTEMIS ARENA			
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Lunabotics Project Partners		
Name	**Support**	**Email**
Rob Mueller	Chief Judge	rob.mueller@nasa.gov
Rich Johanboeke	KSC Project Manager	richard.m.johanboeke@nasa.gov
Kurt Leucht	KSC The Voice of Lunabotics	kurt.leucht@nasa.gov
Mike Miller	KSC Communications Chief	michael.j.miller@nasa.gov
Eric Reiners	KSC Lead Judge, Autonomy	Reiners_Eric_A@cat.com
Rebecca Mazzone	KSC Lead Judge, Presentations and Demonstrations	rebecca.mazzone@nasa.gov
Amanda Hipple-Bornhorn	KSC Lead Judge, STEM Engagement Report	amanda.e.hipple-bornhorn@nasa.gov
Jonette Stecklein	KSC Lead Judge, Systems Engineering Paper	jonette.m.stecklein@nasa.gov
Bill Dearing	KSC Communications, Judge Emeritus	dearingtech@gmail.com
Theresa Martinez	KSC Presentations and Demonstrations, Judge Emeritus	theresa.c.martinez@nasa.gov
Vanessa Stroh	KSC PIT BOSS	vanessa.l.stroh@nasa.gov
Gloria Chestnut	KSC Artemis Arena Chief	dromyka@yahoo.com
Al Gibson	KSC Environmental Protection Specialist	albert.e.gibson@nasa.gov
Rebecca Mazzone	KSC Mission Control Director	rebecca.mazzone@nasa.gov
Carla Rosenberg	KSC Senior Project Coordinator	carla.b.rosenberg@nasa.gov
Carol Taecker	KSC Education Coordinator	carol.j.taecker@nasa.gov
Dario Torres	NASA Office of Protective Services, K-9 Handler	dario.torres@nasa.gov
Michael Olsen	NASA Office of Protective Services, K-9 Secuirty Officer	michael.t.olson@nasa.gov
Christopher Vaughn	NASA Office of Protective Services, K-9 Supervisor	christopher.d.vaughn@nasa.gov
John Stubbe	NASA Office of Protective Services, Special Agent	john.w.stubbe@nasa.gov
Kristina Brink	KSC COR KSC Visitor Complex	kristina.m.brink@nasa.gov
Carlray Boswell	KSC Asst. Chief of Fire Prevention	carlray.boswell-1@nasa.gov
John Trautwein	KSC AST, Technical Management (PDL)	john.k.trautwein@nasa.gov
Megan Wilson	KSC Fire Inspector	megan.c.wilson@nasa.gov
Amy Lombardo	KSC Graphics	amy.d.lombardo@nasa.gov
Lorraine Santiago-Aguayo	KSC Industrial Hygiene	lorraine.m.santiago-aguayo@nasa.gov
James Dean	KSC KIAC Logistics Operations (radios)	james.a.dean@nasa.gov
Devon West Seago	KSC Legislative Affairs Specialist	devon.m.west@nasa.gov
Christopher Stevens	KSC Public Affairs Specialist	christopher.j.stevens@nasa.gov
Derrol Nail	KSC Public Affairs Specialist	derrol.j.nail@nasa.gov
Amanda Griffin	KSC Supervisory Public Affairs Specialist	amanda.griffin@nasa.gov
Christopher Minshall	KSCVC Delaware North Park Services	CMinshall@delawarenorth.com
Megan Bryan	KSC NSPIREHub Event Coordinator, Volunteers	megan.c.bryan@nasa.gov
Chris Albritton	The Astronaut Memorial Foundation	christan.a.albritton@nasa.gov
Chris Albritton	The Astronaut Memorial Foundation	calbritton@amfcse.org
Isabel Kennedy	The Astronaut Memorial Foundation	isabel.kennedy@nasa.gov
Isabel Kennedy	The Astronaut Memorial Foundation	ikennedy@amfcse.org
Thad Altman	The Astronauts Memorial Foundation, CEO	taltman@amfcse.org
Parks Easter	UCF, Exolith Lab, Chief Geotechnical Engineer	Parks.Easter@ucf.edu
Margot Winick	UCF, Communications Manager	margot.winick@ucf.edu

CONSTRUCTION – TWO ON-SITE EVENTS

The goal is to gather data on lunar construction by designing and building a robot that will traverse the chaotic Lunar terrain and construct a regolith simulant-based berm. The task is to build a berm structure that would be useful to the Artemis Mission for blast and ejecta protection during lunar landings and launches, shading cryogenic propellant tank farms, providing radiation protection around a nuclear power plant, and other mission-critical uses.

Event 1 – Construction Challenge at the University of Central Florida
The Lunabotics Qualification Challenge

Selected teams will first attend this challenge located at the University of Central Florida, held at UCF's Florida Space Institute's Exolith Lab® in Orlando, Florida (532 S. Econ Cir, Oviedo, FL 32765). You can find current and complete information about UCF's Lunabotics Qualifying Challenge here.

Event 2 – Construction Challenge at the Kennedy Space Center

The 10 highest-scoring teams from the UCF Qualifying Event will be invited to bring their robot and finish the competition here. All other participants are invited to attend the final robot runs, participate in lectures, seminars, and workshops which will be provided with passes to the Kennedy Space Center Visitors Complex (KSCVC). KSCVC information on attractions, parking, and restaurants can be found Here.

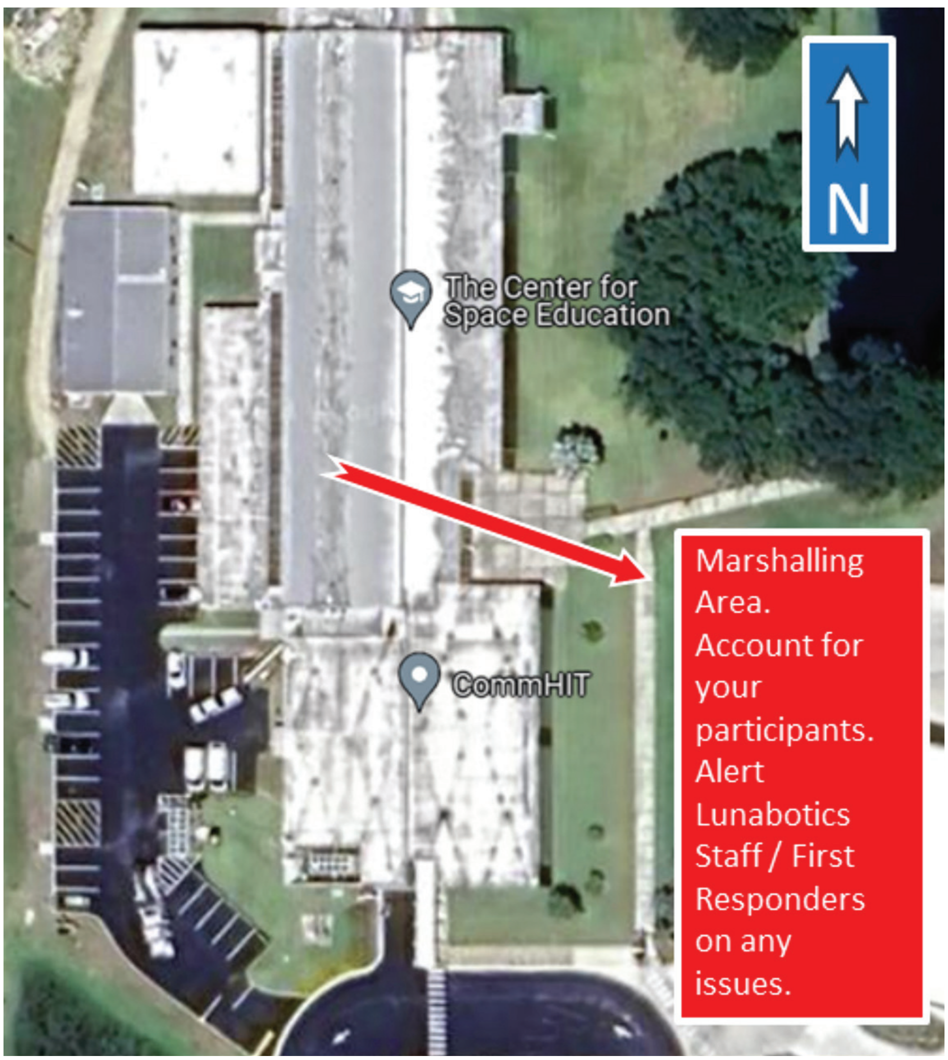
FIRST RESPONDERS

Calling First Responders

- Remain Calm. If you see something, say something.
- Notify the Pit Boss, Arena Chief, Mission Control Director, Lunabotics Staff.
- If in doubt, call KSC First Responders (fire, paramedics, etc.) at 321.867.7911.
- Tell them why you are calling, answer their questions, and tell them you are located in the Astronauts Memorial Foundation's Center for Space Education, Building M6-306, located on the west side of the Kennedy Space Center Visitor Complex.
- Get people to meet and guide the First Responders to where you are located. There is no judgment on calling for First Responders. Remain Calm.

Marshalling Area

If you are directed to leave the facility for whatever reason, do not hesitate, do not delay, exit the facility, and head over to the east side of the facility designated as the Marshalling Area. Advisors and Team Leads account for your participants. If there is an issue, immediately notify the Lunabotics Staff and or the KSC First Responders.



MISCELLANEOUS

1. **Fire Exits / Eyewash Stations**
   Know where the fire exits, fire extinguishers, and eyewash stations are located.

2. **Kennedy Space Center Visitor Complex Accessibility Information Page**
   This page is available for students / faculty / guests with special needs that may be joining us for the challenge. You are under no obligation to self-identify, but if you want to discuss accessibility issues, please send your inquiries to ksc-lunabotics@mail.nasa.gov .

3. **Military Containers (ammo cans)**
   Spray paint or cover up the former military content signage to avoid any extra security checks.

4. **Controlled Substances**
   The consumption of alcoholic beverages or use of any controlled substances by a participant during the event is prohibited. Violation is grounds for disqualification.

5. **Weapons**
   No weapons of any kind are permitted inside Kennedy Space Center Visitor Complex. (contact John Stubbe, KSC Protective Services at john.w.stubbe@nasa.gov) for more information.) 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.

6. **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.

7. **Wildlife**
   There are alligators, ants, armadillos, mosquitoes, raccoons, snakes, and wild hogs. Do not attempt to feed or interact with the wildlife in any manner.

8. **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. Remember to have hats, sunglasses, insect repellent, sunscreen (SPF 50 or better), and a raincoat/poncho on hand for the competition. Giant Voice will issue weather alerts for the following lightning conditions:

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

DAILY SCHEDULE

Lunabotics Daily Schedule (Subject to Change)				
Time		May 20	May 21	May 22
0630	AM	Staff Check-In	Staff Check-In	Staff Check-In
0700	AM	Check-In	Pits Open	Pits Open
0800	AM	Judges Meeting	Judges Meeting	Judges Meeting
0900	AM	Opening Ceremony	Construction Run 6	Construction Run 4
1000	AM	Robot Inspections	Construction 7	Construction 5
1100	AM	Robot Inspections	Construction 8	Construction 6
1200	PM	Lunch	Lunch	Lunch
1300	PM	Construction Run 1	Construction Run 9	Construction Run 7
1400	PM	Construction Run 2	Construction Run 10	Construction Run 8
1500	PM	Construction Run 3	Construction Run 1	Construction Run 9
1600	PM	Construction Run 4	Construction Run 2	Construction Run 10
1700	PM	Construction Run 5	Construction Run 3	
1800	PM	Pits Close	Pits Close	Award Ceremony

ON-SITE WEEK

Day 1, 0700 – 0800 Tuesday, May 20, 2025

College Team Check-In, opening ceremony, seminars, run construction robots. 10 teams and 120 students and faculty will check in from 0700 – 0800. An additional 200 students and faculty members are expected to attend this event and will check in during normal KSCVC hours.

Day 2, 0700 – 1800 Wednesday, May 21, 2025

Seminars, run construction robots.

Day 3, 0700 – 1800 Thursday, May 22, 2025

Seminars, run construction robots, award ceremony. The award ceremony may be held in the Central Conference Room. The location of the award ceremony may change based on mission and other factors.

Lunabotics participants who want to attend the on-site event at KSC must do the following (this applies to all teams): have your faculty advisor/team lead of record send one list of names (last, first, middle Initial) to ksc-lunabotics@mail.nasa.gov by Wednesday, May 07, 2025. Tickets and passes will be reserved based on this information. Each team will be allocated 15 tickets. If more are needed, we can have a discussion.

Kennedy Space Center Visitor Complex, Florida

Day 1 – Check-In

Enter the KSCVC entrance, show your parking pass, and proceed to Parking Lot 4. Go to the check-in tent, located on the left side of the main entrance, next to the picnic benches. The faculty advisor and team members shall check in together at the same time, with no exceptions.

Remember, we move spaceflight hardware and launch rockets. The Kennedy Space Center is an operational range with mission and security having priority. Please be patient during delays.

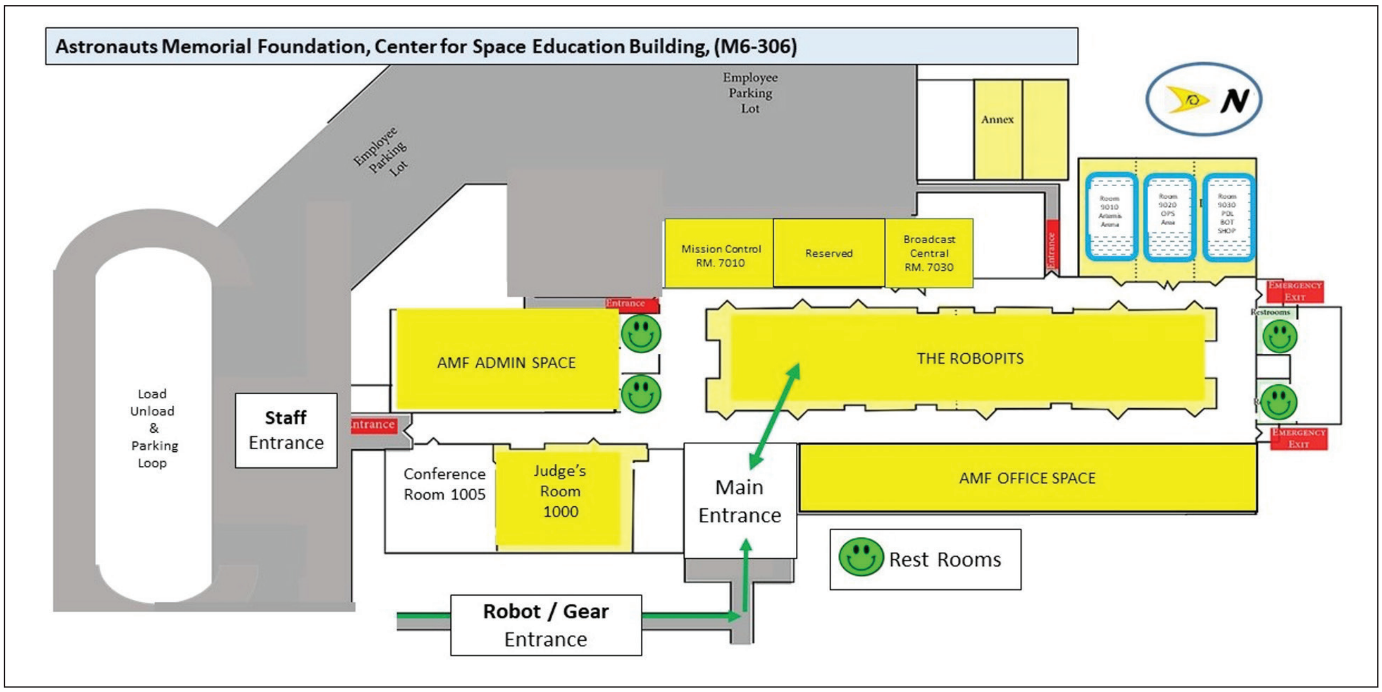
1. Photo Identification
   The following are acceptable:
   - Foreign passport.
   - Permanent resident card or alien registration receipt card (Form I-551).
   - PIV card.
   - State-issued driver's license or ID card.
   - Tribal ID card.
   - U.S. military dependent's ID card.
   - U.S. military ID card.
   - U.S. passport.

2. School ID cards cannot be accepted. Damaged ID cards and blurred images cannot be accepted. For students walking into the Complex through security and the magnetometers, leave your equipment tools, wire cutters, nibblers, moopsies, etc., in your vehicle.

3. Check-in staff will direct the students to proceed to the KSCVC Main Entrance and then on to the CSE unloading area.

4. Check-in staff will direct the robots/gear / etc., and one driver will remain with the vehicle. Please comply with the directions from security.

5. Meet your vehicle(s), unload gear, and proceed to the CSE main entrance located on the east side of the building. Proceed to the RoboPits and have the faculty advisor/team lead meet with the Pit Boss for further directions.



Map of the CSE, RoboPits and Artemis Arena

Days 2 and 3 – Competition Days

On these days, show the parking pass to the parking attendant and proceed to the KSCVC Main Entrance. Team members shall show their tickets tp enter the Complex's main entrance and proceed to the CSE.

1. Check-Out Robots and Equipment
   There is only one check-in. Robots can check-out at any time but will not be allowed back into the challenge.

2. Tours/Groups
   There may be press, elected officials, NASA HQ representatives, families, STEM 8-12 students, and others touring the CSE during the challenge. Remember, when things go south, and they will, remain professional.

ADDITIONAL ACTIVITIES

There will be various seminars/workshops throughout the week that may include the following topics:

Systems Engineering Seminar

How to Produce a Perfect Lunabotics SE Paper (and How to Win the Whole Competition)

Systems 'd'esign - How All the Systems Engineering Tools Work Together

IPEX Overview

- KSC Swamp Works lunar rover designed for excavation)
- Overview of the ISRU Pilot Excavator (IPEx)
- Design of the IPEx
- Mission Concept of Operations
- Simulation work of IPEx in lunar environment collaboration with Caterpillar
- Demonstration of IPEx's predecessor RASSOR in the Competition Arena
- IPEx on display (possible)
- Announcement of new student competition involving IPEx

Autonomy Seminars

- Q&A with Caterpillar Autonomy Technologists
- 30-minute segments
- 15 mins - students present their autonomy system/questions
- 15 mins - Q&A exchange with CAT Autonomy Technologists
- First come first serve signup
- Open venue
- Learn from each other

UCF - Bootstrapping of the Solar System Economy through the use of Space Resources.

KSC - Tech Transfer University

KSC - NASA Internships

… and many more!

GLOSSARY OF TERMS

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

2. **Artemis Arena**: Located in the Astronaut Memorial Foundation's Center for Space Education (CSE) where the robots will perform each competition attempt. The arena area measures ~6.8 m long and ~5m wide and contains ~45 cm of Black Point-1 (BP-1) (basalt regolith simulant).

3. **Astronaut Memorial Foundation's Center for Space Education (CSE)** (https://www.amfcse.org/about-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.

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

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

6. **Black Point-1 (BP-1)** (https://ares.jsc.nasa.gov/projects/simulants/bp-1.html): both parameters (coefficient of friction and cohesion) are highly dependent on the humidity and compaction (bulk density, porosity) of the Lunar soil. Note the following:
   - It does not behave like sand.
     The coefficient of friction has not been measured.
   - There are naturally occurring rocks in the aggregate.
   - BP-1 is made from crushed basalt fines and not commercially available.
   - See "Soil Test Apparatus for Lunar Surfaces"
   - The density of the compacted BP-1 aggregate will be between 1.5 g/cm3 and 1.8 g/cm3.
   - BP-1 behaves like a silty powder soil with most particles under 100 microns in diameter.
   - Will be compacted and the top layer will be raked to a fluffy condition of approximately 0.75 g/cm3, similar to the Lunar surface.
   - Teams are encouraged to develop or procure simulants based on basaltic minerals and lunar surface regolith particle size, shape, and distribution.

7. **Center for Lunar & Asteroid Surface Science (CLASS)** (https://sciences.ucf.edu/class/): is at the intersection of NASA science and exploration for rocky, atmosphereless bodies.

8. **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.

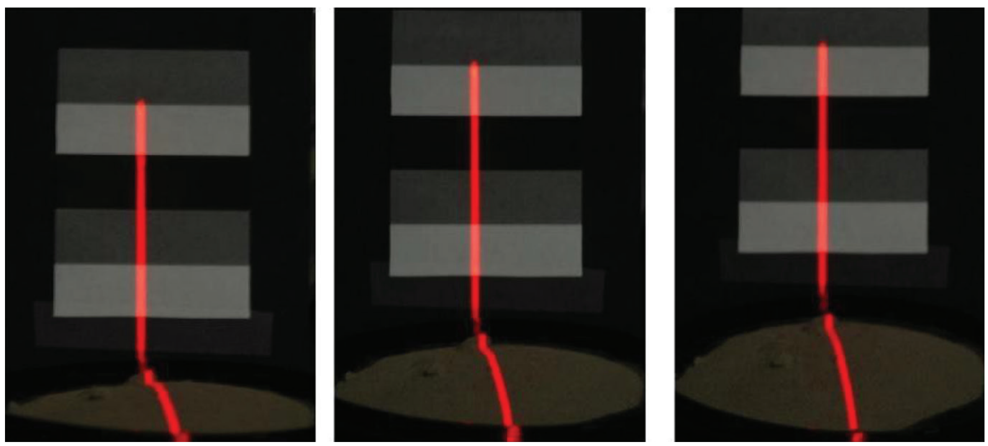
9. **Bot Shop** (https://public.ksc.nasa.gov/partnerships/capabilities-and-testing/testing-and-labs/prototype-development-laboratory/): the Prototype Development Laboratory's (PDL) Bot Shop is a "mobile machine shop" with grinding, sanding, mini-mill and mini-lathe, band saw, drill press and hand tools. There is no welding capability. Help teams in repairing broken robots but do not have the capability to finish a started robot. The Bot Shop is busy throughout the competition.

10. **Exolith Lab** (https://exolithsimulants.com/): enable space development and growth by providing high-fidelity analogs to researchers and educators globally. "Space Resource Technologies (Space Resource Technologies)-enable space development and growth by providing high-fidelity analogs to researchers and educators globally. Lunar Highlands Simulant LHS-2E ((LHS-2E) Engineering Grade Lunar Highlands Simulant – Space Resource Technologies) has been developed by Space Resource Technologies as a high fidelity, mineral-based simulant appropriate for the average highlands location on the Moon."

11. **In-Situ Resource Utilization (ISRU)** (https://beta.nasa.gov/mission/in-situ-resource-utilization-isru/): To live and work in deep space for months or years may mean crew members have less immediate access to the life-sustaining elements and critical supplies readily available on Earth. However, the farther humans go into deep space, the more important it will be to generate products with local materials,

12. **Kennedy Space Center Visitor Complex (KSCVC)** (https://www.kennedyspacecenter.com/): As a Smithsonian Affiliate, we offer the chance to view artifacts of NASA's Mercury, Gemini, Apollo and Space Shuttle Programs in the context of exhibits and attractions that tell the NASA story.

13. **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.



10 Degree, 16 Degree, 21 Degree
LIDAR/Laser Deflection

14. **NASA Gateway OSTEM Application Website** (https://stemgateway.nasa.gov/public/s/explore-opportunities/challenges): the Team Lead starts the team application process and then invites students and faculty advisor(s) to apply within the website. When you run into an issue on the NASA Gateway OSTEM application website, send your inquiries to the website Help Desk.

15. **Regolith Construction 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

16. **Regolith Construction Points:** Points earned from the competition attempt will be used to determine ranking in the on-site robotic operations category.

17. **Mission Control:** Mission Control is the operations area where teams will operate or autonomously control their robotic excavator to simulation a lunar In-Situ Resource Utilization (ISRU) construction mission. It is located outside of the Artemis Arenas. Only students from the team are allowed into the Mission Control Rooms during the robot run. A team will be disqualified for having faculty / advisors or non-team members in the mission control room during the robot run.

18. **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.

19. **RoboPits:** The RoboPits are equipped with emergency eyewash stations and disposal containers for industrial waste. 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 your robot gets inspected before it goes to work.

20. **Rock/Gravel:** The gravel is #57 limestone gravel (~2 cm in diameter) and is intended to simulate the icy-regolith buried in the South Polar region of the Moon. It 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.

21. **Swamp Works**: The Swamp Works is a lean-development, rapid innovation environment at NASA's Kennedy Space Center. It was founded in 2012, when four laboratories in the Surface Systems Office were merged into an enlarged facility with a modified philosophy for rapid technology development.

22. **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.

23. **University of Central Florida (UCF)** (https://www.ucf.edu/): The University of Central Florida is a public research university with its main campus in unincorporated Orange County, Florida. It is part of the State University System of Florida.

FROM GOOGLE SCHOLAR

1. NASA's Plan for Sustained Lunar Exploration and Development
https://www.nasa.gov/sites/default/files/atoms/files/a_sustained_lunar_presence_nspc_report4220final.pdf

2. Nasa Lunabotics Robotic Mining Competition 10th Anniversary (2010-2019): Taxonomy Technology Review
https://ntrs.nasa.gov/citations/20200003009

3. Novel Approaches to Drilling and Excavation on the Moon
https://arc.aiaa.org/doi/pdf/10.2514/6.2009-6431

4. Preparing for Mars: Evolvable Mars Campaign "Proving Ground" approach
https://ieeexplore.ieee.org/abstract/document/7119274

5. NASA Human Spaceflight Architecture Team: Lunar Surface Exploration Strategies
https://ntrs.nasa.gov/citations/20120008182

6. NASA Centennial Challenge: 3D-Printed Habitat
https://ntrs.nasa.gov/api/citations/20170009010/downloads/20170009010.pdf

7. Lunar Spaceport: Construction of Lunar Landing & Launch Pads
https://commons.erau.edu/cgi/viewcontent.cgi?article=1017&context=spaceport-summit

8. Towards In-Situ Manufacture of Magnetic Devices from Rare Earth Materials Mined from Asteroids
https://robotics.estec.esa.int/i-SAIRAS/isairas2018/Papers/Session%2010c/1_iSAIRAS_Ellery_2018_final-11-40-Ellery-Alex.pdf

9. NASA Centennial Challenge: 3D Printed Habitat, Phase 3 Final Results
https://ntrs.nasa.gov/citations/20190032473

10. A Process Plant for Producing Rocket Fuel from Lunar Ice
https://asmedigitalcollection.asme.org/IMECE/proceedings-abstract/IMECE2019/V006T06A108/1073266

11. Robotic Construction on the Moon
https://ntrs.nasa.gov/api/citations/20210018912/downloads/Design%20for%20Robotic%20Construction%20on%20the%20Moon%20ISU%20SSP%2021%20STRIVES.pdf

12. ISRU: The Basalt Economy.
https://www.researchgate.net/profile/Rodrigo-Romo-2/publication/322567782_ISRU_The_Basalt_Economy/links/5a5fff9c458515b4377b89cb/ISRU-The-Basalt-Economy.pdf

13. RASSOR - Regolith Advanced Surface Systems Operations Robot
https://ntrs.nasa.gov/citations/20150022134

14. Building a Vertical Take Off and Landing Pad Using in situ Materials.
http://ssi.org/2010/SM14-proceedings/Building-a-Vertical-Take-Off-and-Landing-Pad-using-in-situ-Materials-Hintze.pdf

15. Mars Water In-Situ Resource Utilization (ISRU) Planning (M-WIP) Study
https://mepag.jpl.nasa.gov/reports/Mars_Water_ISRU_Study.pdf

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