

NASA'S ROBOTIC MINING COMPETITION (RMC)

RMC: LUNABOTICS 2020

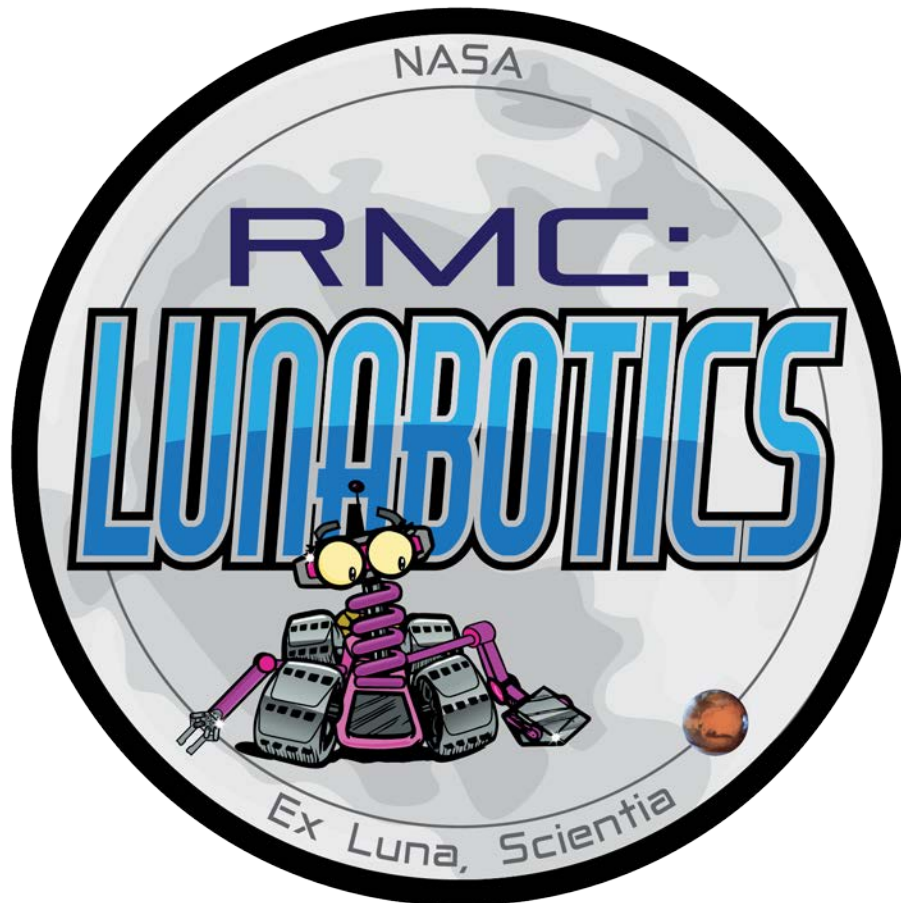


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I. INTRODUCTION

WHY LUNABOTICS?

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

-NASA Administrator Jim Bridenstine

NASA has led the charge in space exploration for more than six decades, and through the Artemis program (<https://www.nasa.gov/what-is-artemis>) we will pave the way to the Moon and on to Mars. The Artemis program is the next step in human exploration. It will enable us to land the first woman and next man on the Moon by 2024, and establish sustainable exploration with our commercial and international partners by 2028. Artemis will secure America's preeminence in space exploration and establish a strategic presence at the Moon. A lunar investment is also an investment in our future: it will create new jobs, help improve life here on Earth, and inspire a new generation and encourage careers in STEM. Furthermore, Artemis is a part of NASA's broader Moon to Mars exploration approach, through which we will quickly and sustainably explore the Moon and enable humanity's next giant leap, human exploration of Mars. On the Lunar surface we will demonstrate technologies, expand commercial opportunities needed for deeper space exploration, and test methods to obtain water from ice and other natural resources to further our journey.

The presence of water at the lunar poles was detected by NASA's Synthetic Aperture Radar (Mini-SAR) on Chandrayaan-1 and confirmed by the Lunar Crater Observation and Sensing Satellite (LCROSS) space probe. Capturing this water is the key to allow humans to live off the land, or in scientific terms, In-Situ Resource Utilization (ISRU). The water can be used for human consumption, hygiene, growing plants, providing radiation shielding and making rocket propellant for the journey home.

NASA's RMC: Lunabotics 2020 is a multi-semester university-level event that supports our Moon to Mars trajectory by requiring teams to participate in four events: (1) present their robot and their design philosophy at the competition; (2) submit a Systems Engineering Paper explaining the methodology used in developing their robot; (3) perform public outreach targeting the under-served, under-represented grade K-12 students in their communities and; (4) design, build and compete a robot to simulate an off-world mining mission.

The complexities of the challenge include the abrasive characteristics of the regolith and icy-regolith simulant, the weight and size limitations of the mining robot and the ability to tele-operate it from a remote Mission Control Center. Points from all the events determine the winner of the Joe Kosmo Award for Excellence.

NASA evaluates over 40 proof-of-concept mining robots every year from the competition. These innovative robotic concepts may result in unique or clever solutions that may be applied to an actual excavation device and/or payload on an ISRU mission. Additionally, our nation will need a future work

force that has the skills for developing autonomous robotic mining on the Moon and other off-world locations. Advances in off-world mining have the potential to contribute to our nation's space vision and NASA's space exploration operations. Our nation will benefit by being leaders in a new space based economy. The systems engineering skills are valuable in other high technology industries that will add to the economic strength of the USA.

Go to NASA STEM Engagement and see all the Artemis Student Challenges at <https://www.nasa.gov/stem/artemis.html> .

II. IMPORTANT NOTICES

CHANGES FOR 2020 COMPETITION

Exception for RMC: Lunabotics 2020 - based on the delay in issuing the Rules and Rubrics.

Teams may still compete if the robot fails the mass and dimensions inspection, the score assigned will be zero (0) mining points for the “Pass All Inspections (Comm/Vehicle)” Mining Category Element. The robot must pass all other inspections (ex: safety, communications, etc.) to compete in the arena.

New Arena Location and Dimensions

The Mining Arena is located in The Astronauts Memorial Foundation’s (AMF) Center for Space Education (CSE).

Arena Dimensions	
Max Length (m)	~5.4
Max Width (m)	~3.6
BP-1, regolith simulant depth (cm)	~30.0
Gravel, icy-regolith simulant depth (cm)	~15.0

The mining arena contain ~45 cm of BP-1 (regolith simulant). The mining zone contains ~30 cm of BP-1 over a ~15 cm bed of gravel (icy regolith simulant), with a mean particle size diameter of ~ 2 cm.

New Robot Dimensions

Robot Dimensions	
Maximum Length (meters)	1.00
Maximum Width (meters)	0.50
Maximum Height (meters)	0.50
Mass (kilograms)	60.00

New Robot Mining Runtime

Robot Runtime	
Robot Arena Set-Up (minutes)	5
Robot Mining Time (minutes)	15
Robot Extraction (minutes)	5

New Supplemental Data – (required)

Provide information about the team's off-world mining robot at:

<https://docs.google.com/forms/d/e/1FAIpQLSeB3v9iz1LoqPW2y1vLgLNIPGSW9Lt6nSRqU9jE3015Cq3C1A/viewform>

New Sieve Measurements

The sieve measures 1.0 m X 0.3 m with the top of the sieve located ~0.5 m above the surface of the mining arena.

FREQUENTLY ASKED QUESTIONS (FAQ)

The FAQ document is updated regularly and is considered part of this document. It is the responsibility of the teams to read, understand, and abide by all of the Rules and Rubrics and FAQs, communicate with NASA's representatives and complete all surveys.

Send questions about the Registration, Rules and Rubrics to RMC: Lunabotics at:

ksc-robotic-mining-competition@mail.nasa.gov

UPDATES

These rules and rubrics are subject to updates. It is the responsibility of the teams to stay current. Please check NASA's Robotic Mining Competition website for updates at:

<http://www.nasa.gov/offices/education/centers/kennedy/technology/nasarmc.html>

III. REGISTRATION

WHO CAN COMPETE?

Collaborations with Registered Teams and Minority Serving Institutions (MSI's)

NASA collaborates with space agencies around the globe on many programs including the International Space Station, Earth observation missions and those headed to the Moon or Mars and other off-world destinations. Building and nurturing an eligible, diverse and inclusive workforce is imperative to the future success of NASA and our Nation.

Lunabotics strongly encourages registered teams to collaborate with each other and teams from schools classified as Minority Serving Institutions (MSIs) by the Department of the Interior (see www.doi.gov/pmb/eeo/doi-minority-serving-institutions-program . Eligible MSIs can be found at <https://www2.ed.gov/about/offices/list/ocr/edlite-minorityinst-list-tab.html> .

Collaborating schools are treated as one, unified team. Award distribution is determined by the arrangement the teams have between each other. Awards to winning collaborating teams would read as follows:

Bending State University in collaboration with Mars University

The Minority Serving Institute (MSI) Capability Gateway is located at <https://msigateway.larc.nasa.gov/>

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 (read the article at www.scientificamerican.com/article/how-diversity-makes-us-smarter/).

Registration

Teams that are from post high school vocational/technical schools, colleges and or universities located in the United States, its Commonwealths, territories and / or possessions are eligible to register for the competition (one team per university campus is allowed). A team must meet the following criteria:

- The team must include undergraduate and/or graduate students (teams must have at least two undergraduate students)
- Students must be enrolled during the current or previous school semester and are in good standing with their school (as certified by the faculty advisor in writing).
- The team must include at least one faculty/staff member who is currently registered with the college or university. Students, faculty and staff not approved by security, cannot be a part of the competition.
- The number of team members on each team is at the discretion of the school. The team should have a sufficient number of members to successfully design, build and operate their mining robot.

- Participants can be members of only one team and each team must have its own working robot(s).
- Each team will have 10 seats for the Award Ceremony. Only registered students and registered faculty/staff members are eligible to attend the Award Ceremony.

HOW TO REGISTER

Complete the registration process as stated below. There are 50 team slots available on a first come, first complete the process basis. All other teams will be waitlisted, those teams waitlisted must continue to meet all deadlines to remain on the waitlist. Teams deciding to withdraw from the competition will notify RMC: Lunabotics so others team can be offered the opportunity to register for the competition. Submit the following on the Team Registration Form to receive a registration complete email:

1. Email address.
2. Acknowledge the team has read the official Registration, Rules and Rubrics.
3. Team School Name.
4. Team Name.
5. State any official collaboration with another school that is competing.
6. Dean's Letter of Support (PDF Format) - Each team must upload a SIGNED Letter of Support from the lead university's Dean of Engineering.
7. Faculty Advisor's Letter of Support (PDF Format) - Each team must upload a SIGNED Letter of Support from the team's Faculty Advisor.

Start the registration process and remember to meet all due dates at

TEAM REGISTRATION

<http://secorstrategies.com/2020teamlunabotics/>

STUDENT REGISTRATION

<http://secorstrategies.com/2020studentlunabotics/>

FACULTY REGISTRATION

<http://secorstrategies.com/2020facultyunabotics/>

IV: GENERAL COMPETITION INFORMATION

Schedule + Due Dates

All items are due by 12 noon Eastern Time on the date listed – teams failing to meet the deadlines will be removed from the competition.

ITEMS	DUE DATE(S)
Registration Open	Friday Sep 20, 2019
Systems Engineering - Plan for Project Systems Engineering (submit by this date to be eligible for additional 2 pts)	Wednesday Oct 23, 2019
Systems Engineering - Plan for Project Systems Engineering	Monday Nov 04, 2019
Faculty Registration Form	Wednesday Nov 06, 2019
Team Registration Form	Required for Registration
Letter from University's Faculty/Advisor	Required for Registration
Letter from University's Dean of Engineering	Required for Registration
Student Registration Form	Wednesday Nov 06, 2019
Signed Media Release Form	Wednesday Nov 06, 2019
Team Roster	Wednesday Nov 06, 2019
Student Resume (optional)	Wednesday Feb 19, 2020
Team Biography (200 words maximum)	Wednesday Feb 19, 2020
Team Photo with Faculty (jpeg format only)	Wednesday Feb 19, 2020
Corrections to NASA generated Team Roster	Wednesday Feb 19, 2020
Final Team Roster (no changes after this date)	Wednesday Mar 04, 2020
Systems Engineering Paper	Wednesday Apr 08, 2020
Outreach Project Report	Monday Apr 13, 2020
Slide Presentation and Demonstration	Monday May 04, 2020
Robot Details and Proof of Life	Monday May 04, 2020
Supplemental Data	Monday May 11, 2020
ON-SITE COMPETITION WEEK	May 18-22, 2020
Team Check-In, 7 a.m. – 3 p.m. Eastern Time	Monday May 18, 2020
Slide Presentation and Demonstration Days	Tuesday-Friday May 19-22, 2020
Practice Days	Monday-Tuesday May 18-19, 2020
Opening Ceremony	Monday May 18, 2020
Competition Days	Wednesday-Friday May 20-22, 2020
Awards Ceremony Friday Evening	Friday May 22, 2020

COMPETITION COMPONENTS

Plan for Project Systems Engineering – (required)

This is an initial plan for the entire project. The purpose of this plan is to get the team organized and started on the competition. As you execute your project, things will change and your project will evolve. That's okay and expected. In the Systems Engineering Paper you can discuss the changes to your plan and how your project adapted.

Systems Engineering Paper – (required)

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

Slide Presentation & Demonstration – (optional)

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

Public Outreach Project Report – (required)

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

Robotic On-Site Mining – (required)

Teams are required to design and build a mining robot that can traverse the simulated Lunar chaotic terrain. The robot must then excavate the icy regolith simulant (gravel) and return the excavated mass for deposit into the Collector Bin to simulate an off-world mining mission. The teams will have two, 15-minute competition runs to mine the icy regolith. The abrasive characteristics of the basaltic regolith simulant, the weight and size limitations of the mining robot and the ability to tele-operate it from a remote Mission Control Center are some of the additional factors in the competition.

Robot Details and Proof of Life – (required)

This component must include:

- A diagram of the robot and a basic parts list;
- A photo of your robot, which shall be a minimum 1024 x 768 pixels in a JPEG format;

- A link to your YouTube video documenting proof of life. The video is solely for technical evaluation of the mining robot and should cover at least one full cycle of operations including excavation and depositing the material.

Supplemental Data – (required)

Provide information about the team's off-world mining robot as requested at:

<https://docs.google.com/forms/d/e/1FAIpQLSeB3v9iz1LoqPW2y1vLgLNIPGSW9Lt6nSRqU9jE3015Cq3C1A/viewform>

ACCREDITATION BOARD FOR ENGINEERING AND TECHNOLOGY (ABET)

The Accreditation Board for Engineering and Technology (ABET) sets the global standard for programs in applied science, computing, engineering, and engineering technology (<http://www.abet.org>). The Competition rules and rubrics meets the requirements for engineering and engineering technology accreditation.

NASA STEM ENGAGEMENT

See all the NASA STEM Engagement resources available for Educators and Students at <https://cms.nasa.gov/stem/lunar-challenges.html>

RMC: Lunabotics 2020 is one of several opportunities for students to get involved with Artemis STEM Challenges. Going forward to the Moon will be the shining moment of our generation. This moment will belong to you—the Artemis generation. Are you ready? Find out at <https://www.nasa.gov/stem/artemis.html>

SOCIAL MEDIA

See the RMC: Lunabotics 2020 Competition on YouTube, Like us on Facebook and Tweet using #LUNABOTICS2020.

CODE OF CONDUCT

RMC: Lunabotics 2020 is a NASA event and held in a professional, safe and positive environment. Competitors shall be courteous and conduct themselves with integrity and respect to all individuals as required by this event. Competitors shall use sound safety and engineering practices and principles at all times. Behavior inconsistent with this philosophy is unacceptable and shall be grounds for assessment of penalty points, disqualification of an individual and/or of the team. The Project Manager and Head Judge's decision is final.

DISPUTES

Disputes shall be forwarded to the RMC: Lunabotics Project Manager and Head Judge for resolution. The Project Manager and Head Judge's decision is final.

AWARDS

The Efficient Use of Communications Power Award

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

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

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

The Judges Innovation Award

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

The Caterpillar Autonomy Awards – 1st - 6th Places

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

Prizes are awarded to the teams with the first, second, third, fourth, fifth, and sixth most autonomous points averaged from both mining attempts. Not all point levels require icy regolith to be deposited. In the event of a tie, the amount of icy regolith (rock/gravel) deposited will be used to break the tie if possible. If not, the Mining Judges will choose the winner. The fourth, fifth, and sixth places are new to the Caterpillar Autonomy Award. The intent is to incentivize more teams in attempting autonomy.

Systems Engineering Leaps & Bounds Award

Awarded to the team that made a significant improvement over the previous years (or consistently sustained improvement) in their application of systems engineering to the

development of their robot as demonstrated by their systems engineering paper (teams placing in the top 3 are not eligible for this award; not necessarily awarded every year).

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

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

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

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

The Joe Kosmo Award for Excellence

Awarded to the team that scores the most points in all competition events. Joseph Kosmo graduated from Pennsylvania State University in 1961 with a bachelor of science in aeronautical engineering and began his career with the NASA Space Task Group in the Crew Systems Division, working on the Mercury Program spacesuit. During the past 45 years, he has participated in the design, development, and testing of Mercury, Gemini, Apollo, Skylab, and Space Shuttle spacesuits, as well as numerous advanced technology configuration spacesuits and EVA gloves for future mission applications.



Kosmo received the American Astronautical Society's Victor A. Prather Award, the NASA Exceptional Service Medal, and the Astronaut Silver Snoopy Award. He has pursued the development of advanced spacesuits, gloves, and ancillary EVA-supporting hardware concepts for future planetary surface exploration. In 2011, he retired from NASA after a 50-year career in the space industry. This award honors his service and contributions to America's space program.

Award and Point Summary

Efficient Use of Communications Power		Trophy
SSERVI Regolith Mechanics		Trophy
Judges' Innovation		\$1,000.00
Caterpillar Autonomy Award - 1st Place		\$2,000.00
Caterpillar Autonomy Award - 2nd Place		\$1,250.00
Caterpillar Autonomy Award - 3rd Place		\$750.00
Caterpillar Autonomy Award - 4th Place		\$500.00
Caterpillar Autonomy Award - 5th Place		\$250.00

Caterpillar Autonomy Award - 6th Place		\$250.00
Systems Engineering Paper - 1st Place	Up to 25	\$3,000.00
Systems Engineering Paper - 2nd Place		\$2,000.00
Systems Engineering Paper - 3rd Place		\$1,000.00
Systems Engineering Leaps & Bounds		\$250.00
Slide Presentation and Demonstration - 1st Place	Up to 25	\$3,000.00
Slide Presentation and Demonstration - 2nd Place		\$2,000.00
Slide Presentation and Demonstration - 3rd Place		\$1,000.00
Outreach Project Report- 1st Place	Up to 20	\$2,000.00
Outreach Project Report- 2nd Place		\$1,000.00
Outreach Project Report- 3rd Place		\$750.00
Robotic On-Site Mining - 1st Place	Up to 25	\$3,000.00
Robotic On-Site Mining - 2nd Place		\$2,000.00
Robotic On-Site Mining - 3rd Place		\$1,000.00
Joe Kosmo Award for Excellence		\$5,000.00

V. PREPARING FOR COMPETITION WEEK

DAILY SCHEDULE

ON-SITE COMPETITION WEEK, MAY 18-22, 2020	
Team Check-In, 7 a.m. – 3 p.m. Eastern Time	Monday May 18, 2020
Slide Presentation and Demonstration Days	Tuesday-Friday May 19-22, 2020
Practice Days	Monday-Tuesday May 18-19, 2020
Opening Ceremony	Monday May 18, 2020
Competition Days	Wednesday-Friday May 20-22, 2020
Awards Ceremony Friday Evening	Friday May 22, 2020

Robopits are open from 7am – 7pm each day. Lunch each day is from 12pm – 1pm (except Thursday)

Monday	Tuesday	Wednesday	Thursday	Friday
7am Team Check-in	7am – 9am Robot Check-in	7am – 9am Robot Check-in	7am – 9am Robot Check-in	7am – 9am Robot Check-in
9am Inspections open	8am Practice Mining Starts	8am Competition Mining Begins	8am Competition Mining Begins	8am Competition Mining Begins
12 - Noon Opening Ceremony	1pm Practice Mining Resumes	1pm Competition Mining Resumes	11:30am Women in STEM forum	3pm RoboPits Close
1:30pm Practice Mining starts			1:30pm Competition Mining Resumes	3pm Crates Out for Shipping
3pm Team Check-in Closes				5:45pm Bus Loading for Award Ceremony

Check-In Monday

Check-in begins Monday morning at 7am and will close at 3pm local time. Show the parking pass to the attendant and proceed to the check-in tent located in Parking Lot 4 of the Kennedy Space Center Visitor Complex (KSCVC). All vehicles, robots and support equipment must be cleared by security before being allowed into the Complex. The RoboPits and Arenas are located in the Astronauts Memorial Foundation's (AMF) Center for Space Exploration Building (CSE) (M6-306). Check-in staff will direct the teams on how to enter the park.

Check-Out, Monday -Thursday, Robots and Equipment

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

Check-In, Tuesday - Friday, Robots and Equipment

Check-in begins at 7am and will close at 9am local time. The check-In Tent is located in Parking Lot 4 of the Kennedy Space Center Visitor Complex (KSCVC). All vehicles, robots and support equipment must be cleared by security before being allowed into the Complex. Directions will be provided by the Check-In Staff.

Practice Runs for Monday and Tuesday

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

Opening Ceremony

Monday from 12-Noon to 1pm Eastern Time in the RoboPits.

Award Ceremony

The Award Ceremony is held at the KSCVC's Apollo-Saturn V Complex. Buses start loading Friday evening at 5:45pm in front of the Center for Space Education Building. Each team is allocated 10 seats for the Award Ceremony and only registered students and registered faculty are eligible to attend.

SHIPPING YOUR ROBOT

It is the team's responsibility to ship their batteries in accordance with the manufacturer's specifications and comply with all state and Federal regulations. The shipping company is responsible for providing all resources required to load and unload the team's shipment from the shipping vehicle.

Ensure the shipping container is clearly marked with all addresses. The shipping company will go to the NASA KSC Pass & ID Office on the south side of State Road 405. Please have the shipper call 321.749.0320 two (2) hours prior to their arrival and call again on arrival. Central Receiving will send an escort to the shipper. Containers will be accepted between Monday May 11 through Thursday May 14, 2020 between 9 am and 2 pm local time.

Ship To:

NASA John F. Kennedy Space Center
ISC Central Receiving - Bldg. M6-0744
Kennedy Space Center, FL 32899,

Mark For: Lunabotics Competition, AMF Center for Space Education, Building M6-306

After the competition has ended, teams must clearly mark their shipping container with their address for the voyage home and notify their shipping company to pick up their container. Pickup must occur between Tuesday, May 26 and Thursday, May 28, 2020 from 9am to 3pm local time.

Pick-Up From:

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

Do not schedule pick-ups on Saturday, Sunday or federal holidays. Containers left on site will be discarded after Thursday evening May 28, 2020 at 6 p.m. local time.

KSCVC SAFETY

This is a reminder that if your team uses any kind of military container (ex. "ammo cans") please spray-paint or cover up the former military content signage so we can avoid any work stoppages due to extra security checks.

Personal Protection in the Florida Weather

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

Florida is the Lightning Capital of the U.S. the lightning phase conditions are as follows:

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

Unmanned Aerial Vehicles (UAV), Unmanned Aerial Systems

The use of Unmanned Aircraft Systems (Drones) is prohibited at the Kennedy Space Center Visitor Complex (KSCVC) and the Astronauts Memorial Foundation (AMF) Center for Space Education (CSE) under all circumstances. If any member of the team is caught on KSCVC property with these items, the item shall be confiscated and the team member will be removed from the competition. The UAV/UAS will not be returned.

COMPETITION DAY SCHEDULES

Competition Schedule								
Wednesday			Thursday			Friday		
	Arena "A" Channel 1	Arena "B" Channel 11		Arena "A" Channel 1	Arena "B" Channel 11		Arena "A" Channel 1	Arena "B" Channel 11
Start	Team No.		Start	Team No.		Start	Team No.	
8:00 AM	1	2	8:00 AM	43	44	8:00 AM	31	32
8:25 AM	3	4	8:25 AM	45	46	8:25 AM	33	34
8:50 AM	5	6	8:50 AM	47	48	8:50 AM	35	36
9:15 AM	7	8	9:15 AM	49	50	9:15 AM	37	38
9:40 AM	9	10	9:40 AM	1	2	9:40 AM	39	40
10:05 AM	11	12	10:05 AM	3	4	10:05 AM	41	42
10:30 AM	13	14	10:30 AM	5	6	10:30 AM	43	44
10:55 AM	15	16	10:55 AM	7	8	10:55 AM	45	46
11:20 AM	17	18	Lunch			11:20 AM	47	48
Lunch						Lunch		
1:00 PM	19	20				1:00 PM	49	50
1:25 PM	21	22	1:25 PM	9	10	1:25 PM		
1:50 PM	23	24	1:50 PM	11	12	1:50 PM		
2:15 PM	25	26	2:15 PM	13	14	2:15 PM		
2:40 PM	27	28	2:40 PM	15	16	2:40 PM		
3:05 PM	29	30	3:05 PM	17	18	3:05 PM		
3:30 PM	31	32	3:30 PM	19	20	3:30 PM		
3:55 PM	33	34	3:55 PM	21	22	3:55 PM		
4:20 PM	35	36	4:20 PM	23	24	4:20 PM		
4:45 PM	37	38	4:45 PM	25	26	4:45 PM		
5:10 PM	39	40	5:10 PM	27	28	5:10 PM		
5:35 PM	41	42	5:35 PM	29	30	5:35 PM		
(subject to change)								

You must complete your robot inspection and communications check and be cleared by the RoboPit Chief before you can sign up for your competition run. The schedule below is for planning purposes only and is subject to change to meet competition requirements. The updated competition schedule will be sent in the evening prior to the next day's run (see below). Each team is allotted a maximum of 5 minutes to place the mining robot in its designated starting position within the Mining Arena, and 5 minutes to remove the mining robot from the Mining arena after the 15-minute competition attempt has concluded and as directed by the Mining Judge.

PERSONAL SAFETY

Personal Protection in the RoboPits

Remember to use good workshop and engineering practices and principles. RMC: Lunabotics Staff are authorized to issue a STOP WORK Notice to any team on a suspected safety issue and will remain in effect until the Project Manager and or the Head Judge has issued a ruling on the issue. Use eye protection and hearing protection as needed, wear gloves and de-energize robots and equipment as needed. Use the right tool for the right job, bring jack-stands to support your robot (folding chairs are unacceptable), etc. Know where the fire exits, fire extinguishers and eyewash stations are located. Each team is responsible for bringing a First-Aid kit. Report any safety concerns to the RoboPits Chief. All participants are required to don Personal Protective Equipment (PPE) before coming into contact with BP-1 (the regolith simulant). IF YOU ARE ALLERGIC TO TALCUM POWDER, IT IS A GOOD INDICATOR THAT YOU WILL BE ALLERGIC TO THE BLACK POINT-1 (BP-1) REGOLITH SIMULANT.

- **Respiratory:** Respiratory protection is required for participants before coming into contact with BP-1 and must be used in accordance with the manufacturer's operating instructions. The Black Point-1 (BP-1) Lunar Basaltic Regolith Simulant used in the competition contains a small percentage of crystalline silica, which is a respiratory hazard. All participants must use respiratory protection when required to prevent dust inhalation. Respiratory protection must be used in accordance with the manufacturer's operating instructions. Without exception, use of N-95 masks and/or tight fitting negative pressure respirators will require a clean, shaven face. No facial hair shall be in contact with any part of the mask/respirator in order to maintain the seal.
- **Skin & Eye:** The Black Point-1 (BP-1) Lunar Basaltic Regolith Simulant used in the competition is crushed lava basalt aggregate with a natural particle size distribution similar to that of lunar soil. It is alkaline and may cause skin and eye irritation. Personnel should avoid contact with BP-1 and use appropriate skin and eye protection when performing tasks, such as handling dusty robots.

ROBOPITS HOURS AND OPERATION:

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

ROBOPITS PROTOCOL

You are responsible for checking in with the RoboPits Chief upon arrival on Monday morning. The RoboPits Chief will explain the process for inspections, signing up for practice runs, and all RoboPits protocols. The RoboPits Chief is your only point of contact to coordinate practice competition runs. When things get hectic, be professional. The RoboPits Chief will require two contact phone numbers, in case the team needs to be reached at any point during the competition and cannot be found. These numbers will not be shared with anyone and will be disposed of at the end of the competition.

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

RoboPit Guide

- Check robots out with the RoboPits Chief prior to leaving the Complex for the day.
- Teams will need a placard to get through the Complex security gates.
- Check-in the following morning will be 7 am – 9 am, no exceptions.
- Vacuums are provided. They are for use by all teams as needed.
- Return vacuums to the designated area.
- Notify the RoboPits Chief about vacuums that need to be cleaned.
- NASA provided carts are for the use of all teams.
- Teams headed to the arena for competition and going to presentations have first priority on carts. Carts will be designated for these uses.
- Carts are NOT for use in your pit. Carts are not platforms for working on the robots.

- All pits have power strips provided. *Do not daisy chain power strips.*

Competition Runs for Wednesday – Friday

- The competition schedule will be sent out Tuesday afternoon to the team's point of contact. On competition days, teams will be brought to inspection 45 minutes before the scheduled competition run start time.
- It is recommended that the team be ready with the robot on a cart, one (1) hour prior to the scheduled competition start time, to ensure a smooth flow.
- An escort will come to the RoboPit to retrieve the team, do not leave without the escort.
- If the team is not ready or cannot be located, the competition run time will be given to another team that is ready.
- Following the inspection, the escort will take the team to the arena, where arena escorts will take over.
- Presentations and Demonstrations – an escort will come to the RoboPit to retrieve the team approximately 10 minutes prior to the scheduled presentation time, do not leave without the escort.

Clean-up and Check-out

- Each night the RoboPit is expected to be neat, with nothing outside of the pit boundaries. Keep the RoboPit and the surrounding area neat and generally clean, use the provided vacuums as necessary. It is recommended team 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. This process must be complete in order to attend the award ceremony Friday evening.
- Teams will check with the RoboPit Chief no earlier than Wednesday afternoon regarding any issues with shipping the robot after the competition. There will be a designated area for those robots being shipped, do not assume it can be left in your pit.

Waste Accumulation Protocol

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

- Batteries (Alkaline, Lithium, Ni-Cd)
- Oily wipes/IPA solvent wipes
- Solder waste

- Acetone wipes
- PCV cement – brushes, wipes, and cans
- PVC primer – brushes, wipes, cans
- Super Glue
- Epoxy Tubes
- Aerosol Cans
- Spray Paint
- Pray Foam
- Spray Adhesives
- WD40
- PB Blaster
- Silicone Spray
- Oil Cans
- 3 in 1 oil

Regulations can be found at:

<https://www.epa.gov/hww>

<https://floridadep.gov/waste/permitting-compliance-assistance/content/hazardous-waste-management-main-page>

THE BOT SHOP

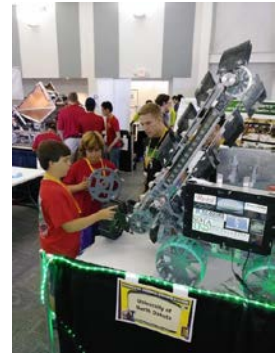
The Prototype Development Laboratory's (PDL) Bot Shop is a "mobile machine shop" with grinding, sanding, mini-mill and mini-lathe, band saw, drill press and hand tools with no welding capability. They can help repair broken robots but do not have the capability to finish a started robot and only NASA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

Bot Shop Hours:

- Monday: 12pm – 5pm
- Tuesday – Thursday: 9am – 5pm
- Friday: 9am – 12pm

THE TEST BED (SAND BOX)

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



FAMILY AND FRIENDS VIEWING THE COMPETITION

The Kennedy Space Center Visitor Complex (KSCVC) opens at 9 am. If you have family or friends that want to see your robot run and your run time starts before the park opens at 9 am, you need to notify the Project Management Staff to make arrangements the day before the run. Your family or friends must have a valid KSCVC Admission Ticket for that day.

VI. SCORING AND RUBRICS

PLAN FOR PROJECT SYSTEMS ENGINEERING – UP TO 2 BONUS POINTS TOWARDS THE SYSTEMS ENGINEERING PAPER

This is an initial plan. As you execute your project, things will change and your project will evolve. That's okay and expected. In your Systems Engineering Paper you can discuss the changes to your plan and how your project adapted. Maximum length of the plan is 5 pages.

The Plan will be scored as identified below. Final Plan score will be divided by 5 to determine the Systems Engineering Paper bonus points. The final Systems Engineering Paper score will not exceed 25 points. Bonus points towards Systems Engineering Paper are only available to those who meet the initial deadline for the SE Plan.

- **Initial Project Schedule (3 points)**
- **Initial Project Budget (3 points)**
- **Design Optimization Criteria (1 point)**
- **Initial Technical Performance Measures (3 points)**

Scoring Rubric - Plan for Project Systems Engineering – UP TO 2 BONUS Points toward Systems Engineering Paper	
Element	Points
<p>Initial Project Schedule (3 points)</p> <p>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.</p> <p>1) Start Date</p> <p>2) Completion Date: (after project decommissioning; this is the date when you have disposed of your robot system after the competition; e.g., you hand the system over to next year's team, broke it down for scrap, threw it in the trash, etc.)</p> <p>3) Major review milestones (as a minimum, these must include Systems Requirements Review, Preliminary Design Review, Critical Design Review; others may be identified as you find appropriate)</p>	<p>There are 3 points total for 6 elements</p>

<p>4) Competition product delivery dates to the Lunabotics Engineering Competition, including the planned date to submit “Robot Details/Proof of Life” to the Lunabotics Engineering Competition.</p> <p>5) Important milestones related to Project Cost Budget and Technical Performance Measurement budget as identified in the Initial Project Budget and Initial Technical Performance Measurement budget</p> <p>Optionally, you may also identify any major Systems Engineering activities in your Initial Project Schedule.</p> <p>6) Discuss how you will manage the evolution of the schedule during the life of the project (how often and when you will review project progress, and how you will adapt to schedule slips or schedule advance opportunities).</p>	
<p>Initial Project Cost Budget</p> <p>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.</p> <p>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.)</p> <ul style="list-style-type: none"> a. Cost estimates for elements in the earliest level System Hierarchy b. Labor costs, if any c. Material costs for competition (for production and completion of RMC deliverables) d. Travel costs to KSC <p>2) Critical scheduling milestones for budget items or other categories if any.</p> <p>[These should be reflected in item 5 for the Initial Project Schedule; e.g., dates funds will be needed, planned activities to raise funds, etc.]</p> <p>3) Discuss how you will manage the evolution of the budget during the life of the project (how often you will review budget progress and when, and how you will adapt to budget shortfalls or possible cost savings should they occur).</p>	<p>There are 3 points total for 3 elements</p>

<p>Design Optimization Criteria</p> <p>Provide a short discussion, in the context of systems engineering, of what your team intends to optimize in your robot system design and operations (e.g., low mass, automation, collection of icy regolith simulant, low bandwidth, etc.)</p>	<p>There is 1 point for 1 element.</p>
<p>Initial Technical Performance Measures (Technical Budgets)</p> <p>Provide Table of Technical Performance Measures that you deem are important to your design approach (e.g., mass, size, bandwidth, speed, etc.) including the following as a minimum. Discuss only as needed.</p> <ol style="list-style-type: none"> 1) Identification of Technical Performance Measures 2) Initial Target for each Technical Performance Measure to be achieved by the competition 3) Allocation of each Technical Performance Measure across the elements of the earliest System Hierarchy 4) Discuss any critical schedule milestones for achieving critical technical performance levels (e.g., decision points in the design process where if you are unable to achieve for example a certain total mass, you would change the design). [These should be reflected in item 5 for the Initial Project Schedule.] 5) Discuss how you will manage the evolution of the Technical Performance Measurement budgets during the life of the project (how often will review technical budget item progress, and how you will adapt to performance shortfalls should they occur). 	<p>There are 3 total points for 5 elements.</p>

Systems Engineering Paper – 25 Points

Each team must submit a Systems Engineering Paper electronically in PDF. The purpose of the systems engineering paper is for a team to demonstrate how they used the systems engineering process in designing, building and testing their robot. All required elements of the rubric must be discussed in the main body of the paper; you may reference the appendix and provide supporting information there. A minimum score of 20 out of 25 possible points must be achieved to qualify to win in this category. In the case of a tie, the judges will choose the winning Systems Engineering Paper. The judges' decision is final. For reference, undergraduate course materials in NASA Systems Engineering are available at www.spacegrant.org.

Scoring Rubric - Systems Engineering Paper – 25 Points	
Element	Points
<p>Content (3 Points)</p> <p>1) Format: The Lunabotics Engineering Competition Systems Engineering Paper shall be formatted professionally as if for submission to a professional journal: organized clearly so that each required rubric element is easy to find; with correct grammar and spelling; with text no smaller than size 12 point font in the main body and appendices; text no smaller than size 9 point font in graphics and tables; using professional journal margins; single spaced; and, consist of a maximum of 20 pages in the main body not including the cover page, title page, table of contents, and references pages. Up to five additional pages of appendices shall be allowed and shall be referenced and discussed in the main body.</p> <p>Only the first 20 pages of the main body and the first five pages of appendices will be subject to judging.</p> <p>The cover page must include: team name, title of paper, full names of all team members, university name, and faculty advisor's full name.</p> <p>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.</p> <p>3) Reason for using Systems Engineering: A statement shall be included early in the main body explaining the reason the team used systems engineering in the NASA Lunabotics Engineering Competition (beyond that it is required). (e.g. What benefit did it provide? How was systems engineering valuable to your project?)</p>	<p>There are 3 points for 3 elements, one point each</p>
<p>Project Management Merit (8 points, 2 bonus points possible)</p> <p><u>1)</u> Design Optimization Criteria: In the context of systems engineering; discuss what your team intends to optimize in your robot system design and operations (light weight?</p>	<p>8 points for 5 elements.</p>

<p>automation? collection of icy regolith simulant? low bandwidth? etc.) (one point)</p> <p>2) New Design or Design Update: Clearly identify the new elements in this competition year's robot system (either state that the robot system is an entirely new design, or identify the specific subsystems or components that were changed on a previous robot system). Explain how you arrived at your decision for these changes to a previous design. Focus the rest of the paper on the systems engineering work you performed to develop the new/updated subsystems/components and incorporate them into the whole system to perform the mission. (two points)</p> <p>3) Major reviews: At a minimum, descriptions of how the System Requirements Review (SRR), Preliminary Design Review (PDR), and Critical Design Review (CDR) were conducted, and how the system design and project plans changed as a result of external reviewers' comments(three points)</p> <p>4) Schedule of work: Discuss the project schedule and its evolution from inception to disposal of robot system (original planned schedule before project start: actual schedule performance with schedule changes tracked against the original schedule, reported as a minimum at major reviews). Demonstrate in the discussion that the schedule was used to manage the project. (one point)</p> <p>5) Cost budget: Discuss the budget and its evolution for total project costs including travel; estimated predicted costs before project start, with actual costs tracked against estimated, reported as a minimum at major reviews as the project matures (one point)</p>	<p>2 bonus points may be awarded for exceptional work on Project Management Merit elements</p>
<p>Systems Engineering Merit (8 points for 8 elements, one for each element. Four bonus points possible.)</p> <p>1) Concept of operations (Describe how the robot system elements at each system hierarchy level will be operated under the environmental conditions of the competition to accomplish the robot system mission)</p> <p>2) System hierarchy (A top-down breakdown of the system design; the elements across each level in the hierarchy should</p>	<p>8 points for 8 elements, one for each element.</p> <p>Up to 4 additional points for exceptional work and additional SE methods used.</p>

<p>be the central topic reviewed and baselined at each control gate or major review)</p> <p>3) Interfaces (Identify key interfaces between system elements in the system hierarchy at each system hierarchy level, including external interfaces)</p> <p>4) Requirements (Identify the key driving requirements for robot system design, operations, interfaces, testing, safety, reliability, etc., stated in proper “shall” language. Address system and lower level requirements. These are the requirements that should be addressed when you discuss verification.)</p> <p>5) Technical Performance Measurement (Identify and discuss technical measures that are important to achieving your Design Optimization Criteria (e.g., mass, power, data, etc.), how they are allocated initially to system elements in the system hierarchy, how they are tracked against the initial allocation reported as a minimum at each subsequent major review as the system matures through verification. Demonstrate the budgeting and management of these important technical quantities throughout the design process.)</p> <p>6) Trade Studies (Discuss how important robot system decisions were made using a trade study methodology, with key decision results captured as robot system derived requirements.)</p> <p>7) Reliability (Discuss design and operations considerations for assuring safety in the event of a system component failure during operations (captured as key driving requirements), and design and operations considerations for assuring successful completion of the competition without a failure.)</p> <p>8) Verification of system meeting requirements (Discuss how you assure or intend to assure that the as built system satisfies, in the context of the concept of operations and under the environmental conditions of the competition, all of the key driving requirements identified and discussed in the paper.)</p>	
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SLIDE PRESENTATION AND DEMONSTRATION – 25 POINTS

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

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

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

Notes on Demonstration

- Safety is of the utmost importance. You are expected to be aware of the specific hazards associated with your robot and plan safe practices for demonstration. Everyone shall adhere to safe practices at all times during the demonstration, especially when troubleshooting unexpected issues in real-time. A clear zone shall be established around the robot, and no one shall enter that zone while the robot is in operation. All content from this paragraph shall be addressed when presenting the “Safety plan” topic.
- “Demonstration” defined: We prefer that you perform a live demonstration of all functions via the control system, however we recognize that this is not always possible. If parts or the entire robot cannot be controlled at the time of demonstration, it is acceptable to move parts by hand (once the power has been turned off), show video from practice runs, etc. to communicate the functionality and attributes of the system and/or subsystems.
- In the presentation room: The competition staff will display the presentation as submitted (see “Dates & Deadlines”); and will provide you with a remote control. An area will be set aside to set up your robot for demonstration. Note: you must move the robot from the cart to support stands if the tracks/ wheels will be operated during the demonstration. Teams may either use the provided supports or bring their own.
- Safety: Re-read the above note on safety, and plan how to safely handle the unexpected!

Scoring Rubric – Slide Presentation and Demonstration – 25 Points	
Elements	Points
<p>Scoring Element 1: Individual Slides</p> <ul style="list-style-type: none"> • Judging Criteria <ul style="list-style-type: none"> ○ Content, Formatting, and Illustrations: Each topic is addressed in sufficient depth. Include illustrations to support slide content (technical content, progression of the project, etc.). Ensure that formatting is readable and there is a good balance of text to graphics. Utilize proper grammar and spelling. ○ Presenter’s Delivery: Body language, preparedness, slide handling, knowledgeable, passion, effective communication. • Topics to Cover: <ul style="list-style-type: none"> ○ Introduction <ul style="list-style-type: none"> ▪ Include team name, university name, names of team members, and faculty advisor’s name. ○ Safety Plan <ul style="list-style-type: none"> ▪ Robot-Specific Details: Discuss hazards and safety features. ▪ Demonstration Safety: Discuss your plan for the demonstration. Include hazards that could be encountered during the demonstration and how you have addressed them to ensure a safe demonstration. ○ Project and System Performance Goals <ul style="list-style-type: none"> ▪ Qualitative ▪ Quantitative: Specify target values/ ranges ○ Project Management – Management of budget, schedule, team, risk, etc. ○ Design and Testing <ul style="list-style-type: none"> ▪ General Philosophy and Process ▪ System-level Alternatives Considered ▪ Subsystem Alternative Analysis and Design Development <ul style="list-style-type: none"> • Mining • Mechanical • Electrical • Software and Controls ▪ Final Configuration ▪ Performance Testing (include comparison of testing results to goals) ○ Innovation: <ul style="list-style-type: none"> ▪ Comparison to last year and evolution from previous years ▪ Identify efforts to evolve processes, features, components, etc. 	<p>There are 15 base points for this element.</p> <p>Lack of “innovation” topic coverage will not count against teams in their first year at the competition.</p>

<p>Scoring Element 2: Overall Package</p> <ul style="list-style-type: none"> • General organization and flow of the slides as a package • General organization and flow between presenters. Time management: appropriate number of slides and material for time allotted and a professional cadence. • Question and Answer session • Overall Performance 	<p>There are 6 base points for this element.</p>
<p>Scoring Element 3: Demonstration</p> <ul style="list-style-type: none"> • Live demonstration will not be permitted if the “Demonstration Safety” component of the Safety Plan was not addressed prior to the intended movements. • Scoring: <ul style="list-style-type: none"> ○ Pass/Fail criteria: <ul style="list-style-type: none"> ▪ Adherence to the safety plan. ▪ Executing the demonstration safely. ○ Extent of organization, integration, and planning ○ Extent of demonstration ○ Depth of explanation 	<p>There are 4 base points for this element.</p> <p>Failure to adhere to safe practices will automatically result in a score of “0” points.</p>

PUBLIC OUTREACH PROJECT REPORT – 20 POINTS

Each team must participate in an *educational* outreach project in their local community to engage students in STEM (Science, Technology, Engineering and Math). We are returning to the moon as a new generation of explorers, this time to stay. Outreach activities should capitalize on the excitement of NASA’s Artemis program to spark student interest and involvement in STEM and to create enthusiasm as we prepare for humanity’s next giant leap, sending humans to mars. Outreach strategies may include lessons and classroom materials using emerging communications and educational technologies to promote STEM; hands-on science and engineering activities that draw on NASA’s unique missions; and community demonstrations that have a hands-on component involving K-12 students. Teams are encouraged to connect with a diverse student population including women, minorities and persons with disabilities. Each team must submit a report of the Public Outreach Project electronically in PDF by April 13, 2020 at 12:00 p.m. (noon) eastern time. A minimum score of 16 out of 20 possible points must be achieved to qualify to win in this category. In the case of a tie, the judges will choose the winning outreach project. The judges’ decision is final.

Scoring Rubric – Public Outreach Project Report – 20 Points	
Elements	Points
<p><i>Structure, Content and Intrinsic Merit:</i></p> <ul style="list-style-type: none"> Formatted professionally, clearly organized, correct grammar and spelling, size 12 font; single spaced, maximum of 5 pages not including the cover. Appendices are not allowed, however, a link in the body of the report to a multimedia site with additional photos or videos is allowed. Cover page must include: team name, title of paper, full names of all team members, university name and faculty advisor's full name. Purpose for this outreach project, identify outreach recipient group(s). Illustrations must appropriately demonstrate the outreach project. The report <u>must contain a table</u> that includes each event, age/grade level, and number reached 	<p>There are 4 points for 4 elements.</p>
<p><i>Educational Outreach Merit:</i></p> <ul style="list-style-type: none"> The report must effectively describe what the outreach activity(s) was. The report must describe exactly how the Lunabotics Competition team participated, including the number of team members present and the number of hours each team member participated in outreach activities. The report must reflect how the outreach project inspired others to learn about robotics and engineering. The outreach must be STEM focused. The report must demonstrate the quality of the outreach including how hands-on activities were used to engage the audience at their level of understanding. The report must show statistics on the participants. How many children did you reach? What age range/grade-level? Female/male students? EACH EVENT NEEDS STATISTICS. 	<p>There are 10 points for 5 elements.</p>

<p><i>Additional points for exceptional work:</i></p> <ul style="list-style-type: none"> • The report must clearly describe activities, processes, and milestones used to engage underserved and underrepresented populations. • The report must reflect how the outreach project informed students of NASA’s Artemis program and engaged them in understanding that they are the Artemis generation. • The outreach included activities that ignited passion for space exploration, innovation and discovery. • Using survey methodology, the report must provide data on the demographic, geographic, and participant’s perception of the outreach project. • The report must provide a summary of survey comments from each outreach event. • The report must show how you used engineering to improve/enhance either the experience of those you worked with or some aspect of your community. 	<p>There are 6 points for 6 elements.</p>
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MINING, AUTONOMY, AND COMMUNICATION – 25 POINTS

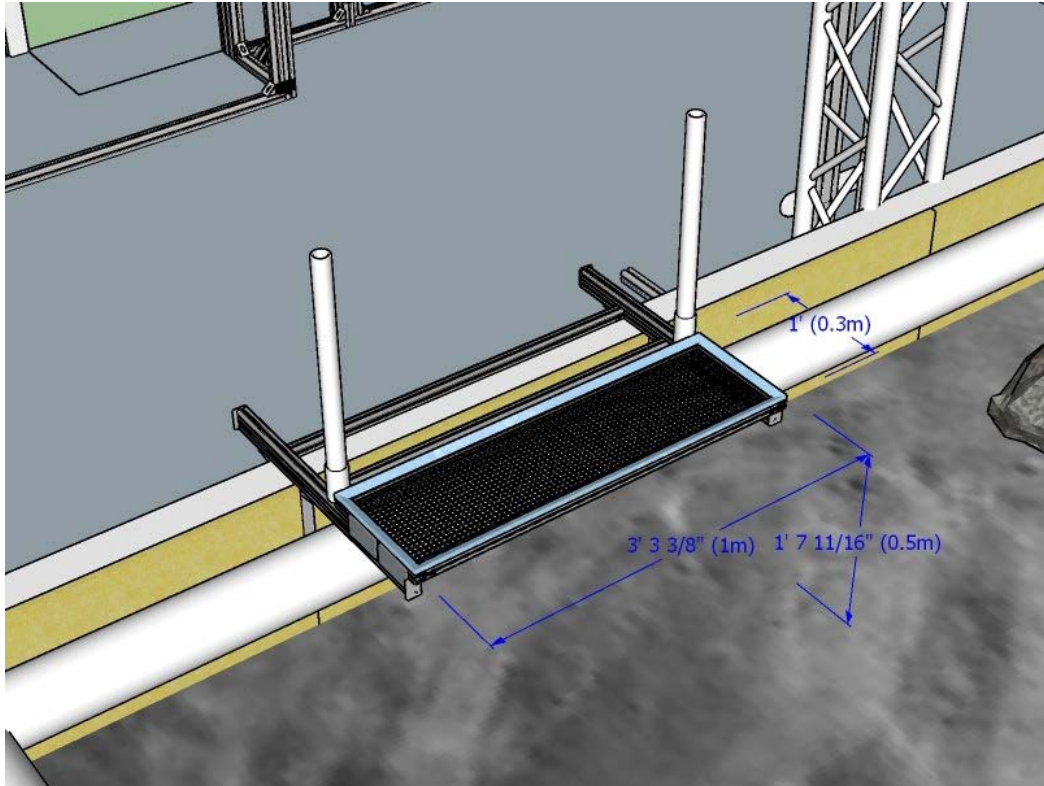
Rules: Mining, Navigation, Autonomy, and Communications

Teams will be required to perform two official competition attempts (15 minutes each) to mine in the arena. A minimum amount of 1.0 kg of gravel must be mined and deposited during either of the two competition attempts to qualify to win in this category. If the minimum amount of 1.0 kg is not met for an attempt, then the total score for that attempt will be 0. In the case of a tie, the teams will compete in a tie-breaking competition attempt. The mining arena contain ~45 cm of BP-1 (regolith simulant). The mining zone contains ~30 cm of BP-1 over a ~15 cm bed of gravel (icy regolith simulant), with a mean particle size diameter of ~ 2 cm. Larger rocks may also be mixed in with the BP-1/gravel in a random manner. Note that the gravel may be mixed in with the BP-1, but the bulk of it will lie under the BP-1 in the mining area. Surface features will consist of craters on each side of the arena with randomly placed boulder obstacles. The craters and boulders will be randomly sized. The mining robot will be placed in the arena in a randomly selected starting position and direction. Each competition attempt will occur with two teams competing at the same time, one on each side of the arena. After each competition attempt, the boulder obstacles and craters will be returned to their starting state.

Mining

- 1) All rock/gravel will be sieved out from the BP-1 at the collector sieve and weighed separately.
- 2) All excavated mass deposited in the collector bin during each official competition attempt will be weighed after the completion of each competition attempt.

- 3) The robot's starting direction will be randomly selected immediately before the competition attempt
- 4) A team's mining robot may only excavate BP-1 and gravel located in that team's respective mining zone at the opposite end of the mining arena from the team's starting area. Mining is allowed as soon as the mining line is crossed by the front end of the robot.
- 5) The mining robot is required to move across the obstacle area to the mining zone and then move back to the collection area to deposit the BP-1 and gravel into the collector sieve.



The sieve measures 1.0 m X 0.3 m with the top of the sieve located ~0.5 m above the surface of the mining arena

- 6) Each team is responsible for placement and removal of their mining robot onto the BP-1 surface. There must be one person per 20 kg of mass of the mining robot, requiring a minimum of three people to carry the maximum allowed mass of 60 kg. Assistance will be provided if needed.
- 7) Each team has a maximum time of **5** minutes to place the mining robot in its designated starting position within the mining arena; and 5 minutes to remove the mining robot from the mining arena after the 15-minute competition attempt has concluded and as directed by the Mining Judge.
- 8) The mining robot operates during the time limit of each competition attempt. The competition attempts for both teams in the mining arena will begin and end at the same time.
- 9) The mining robot will end operation immediately when the power-off command is sent, and as instructed by the Mining Judge.

- 10) The mining robot cannot be anchored to the BP-1 and or rock/gravel surface prior to the beginning of each competition attempt.
- 11) The mining robot will be inspected during the practice days and right before each competition attempt. Teams will be permitted to repair or otherwise modify their mining robots while the RoboPits are open.
- 12) At the start of each competition attempt, the mining robot may not occupy any location outside the defined starting position in the mining arena.
- 13) The mining robot must operate within the mining arena; it is not permitted to pass beyond the confines of the outside wall of the arena during each competition attempt. The gravel must be mined in the mining zone and deposited on the sieve frame. A team that excavates any material from the starting or obstacle areas will be disqualified. The gravel must be carried from the mining zone to the sieve frame by any means and be deposited on the sieve in its raw state. A secondary container like a bag or box may not be deposited on the sieve. Depositing a container on the sieve will result in disqualification of the team. The mining robot can separate itself intentionally, if desired, but all parts of the mining robot must be under the team's control at all times. The robot does not have to re-assemble prior to the end of the competition run. Any ramming of the wall may result in a safety disqualification at the discretion of the judges. The walls may not be used for the purposes of mapping autonomous navigation and collision avoidance (there are no walls on off world locations). Touching or having a switch sensor spring wire that may brush on a wall, or any other surface, as a collision avoidance sensor is not allowed.
- 14) The mining robot must not use the wall as support or push/scoop the gravel up against the wall to accumulate the excavated mass. If the mining robot exposes the mining arena bottom due to excavation, touching the bottom is permitted, but contact with the mining arena bottom or walls cannot be used at any time as a required support to the mining robot. Teams should be prepared for airborne dust raised by either team during each competition attempt.
- 15) The mining robot mass is limited to a maximum of 60.0 kg. Subsystems on the mining robot used to transmit commands/data and video to the telerobotic operators are counted toward the 60.0 kg mass limit. Equipment not on the mining robot used to receive data from and send commands to the mining robot for telerobotic operations is excluded from the 60.0 kg mass limit.
- 16) The mining robot must provide its own onboard power. No facility power will be provided to the mining robot during the competition runs. There are no power limitations except that the mining robot must be self-powered and included in the maximum mining robot mass limit of 60.0 kg. The energy consumed must be recorded with a "Commercial Off-The-Shelf" (COTS) electronic data logger device. Actual energy consumed during each competition run must be shown to the judges on the data logger immediately after the competition attempt.
- 17) The mining robot must be equipped with an easily accessible red emergency stop button or "Kill Switch." Use good engineering practices and principles in placing the "Kill Switch" on your robot(s), failure to do so may result in a safety disqualification. The "Kill Switch" shall have a minimum diameter of 40 mm, it shall be located on the surface of the mining robot and require no additional steps to access it. Only one "Kill Switch" per robot and in the case of multiple robots, each robot will have its

own “Kill Switch.” It shall be easily accessible and activated in an easy and quick manner. Disabling the “Kill Switch” without authorization from the Competition Staff shall result in a safety disqualification. The emergency stop button must stop the mining robot’s motion and disable all power with one push motion on the button. It must be highly reliable and instantaneous. For these reasons an unmodified “Commercial Off-The-Shelf” (COTS) red button is required. A closed control signal to a mechanical relay is allowed as long as it stays open to disable the mining robot. This rule exists in order to have the capability to safe the mining robot in the event of a fire or other mishap. The button should disconnect the batteries from all controllers (high current, forklift type button) and it should isolate the batteries from the rest of the active sub-systems as well. Only onboard laptop computers and data-logger(s) may stay powered on if powered by its internal computer battery.

- 18) The commercial cost of delivering payloads to the Moon is about **\$1.2 Million per kg (2019 est.)**. This competition aims to simulate a lunar mission where a robotic excavator is delivered to the Moon for regolith excavation operations. The mining robot mass is limited to a maximum of 60.0 kg mass. This corresponds to an approximate mission cost of \$72 Million. Lower masses will result in lower mission costs so this competition rewards teams that have a lower robot mass. The robot must be contained within a payload envelope of 1.0 m length x 0.5 m width x 0.5 m height. This corresponds to the typical payload volume available on today’s lunar landers that are commercially available. The mining robot may deploy or expand beyond the 1.0 m x 0.5 m footprint after the start of each competition attempt, but may not exceed a 1.5 meter height. During the excavated mass dumping operations only, the mining robot may deploy itself and exceed 1.5 m in height, but must be lower than the ceiling height, which is 2.5 m above the surface of the regolith.
- 19) To ensure the mining robot is usable for an actual mission, the mining robot cannot employ any fundamental physical processes, gases, fluids or consumables that would not work in an off-world environment. For example, any dust removal from a lens or sensor must employ a physical process that would be suitable for the Lunar surface. Teams may use processes that require an Earth-like environment (e.g., oxygen, water) only if the system using the processes is designed to work in a Lunar environment and if such resources used by the mining robot are included in the mass of the mining robot. Closed pneumatic mining systems are allowed only if the gas is supplied by the mining robot itself. Pneumatic mining systems are permitted if the gas is supplied by the robot and self-contained.
- 20) Components (i.e. electronic and mechanical) are not required to be space qualified for Lunar or atmospheric, electromagnetic, and thermal environments. Since budgets are limited, the competition rules are intended to require mining robots to show an off-world plausible system functionality but the components do not have to be traceable to an off-world qualified component version. Examples of allowable components are: Sealed Lead-Acid (SLA) or Nickel Metal Hydride (NiMH) batteries; composite materials; rubber or plastic parts; actively fan cooled electronics; motors with brushes; infrared sensors, inertial measurement units, and proximity detectors and/or Hall Effect sensors, but proceed at your own risk since the BP-1 is very dusty. Teams may use honeycomb structures as long as they are strong enough to be safe. 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.
- 21) The mining robot may not use any process that causes the physical or chemical properties of the gravel to be changed or otherwise endangers the uniformity between competition attempts.

- 22) The mining robot may not penetrate the BP-1 surface with more force than the weight of the mining robot before the start of each competition attempt.
- 23) No ordnance, projectile, far-reaching mechanism, etc. may be used. The mining robot must move on the BP-1 surface.
- 24) No team can intentionally harm another team's mining robot. This includes radio jamming, denial of service to network, gravel manipulation, ramming, flipping, pinning, conveyance of current, or other forms of attack or damage as decided upon by the judges. Immediate disqualification will result if judges deem any maneuvers by a team as being offensive in nature. Erratic behavior or loss of control of the mining robot(s) as determined by the judges will be cause for immediate disqualification. A judge may disable the mining robot(s) by pushing the red "Kill Switch" or emergency stop button at any time.

Navigation

- 1) Beacons or targets may be attached to the collector sieve frame for navigation purposes only. Tape, clamps or gravity may be used to hold the devices in place. However, the surfaces will have a coating of the BP-1 dust that may interfere with tape adhesion. This navigational aid system must be attached during the setup time and removed afterwards during the removal time period. If attached to the sieve frame, it must not exceed the length of the frame and not weigh over 9 kg.
- 2) The navigational aid system may not be higher than 0.25 m above the sieve frame, and cannot be permanently attached or cause alterations (ex: no drilling, nails, etc.).
- 3) The mass of the navigational aid system is included in the maximum mining robot mass limit of 60.0 kg and must be self-powered.
- 4) The target/beacon may send a signal or light beam or use a laser based detection system. Only Class I or Class II laser or low powered lasers (< 5mW) are allowed. Supporting documentation from the laser instrumentation vendor must be provided to the inspection judges for "eye-safe" lasers.
 - a) The judges will inspect and verify that all laser devices are Class I or II lasers or low powered lasers (< 5mW) and laser based detection system products which have not been modified (optics or power).
- 5) Inertial measurement units (IMU) are allowed on the mining robot. Teams have to explain to the judges how the compass feature will be switched off or the compass data is subtracted to ensure the internal calculations do not make use of the compass (from any magnetic field surrounding the robot).
- 6) Compasses (analog, digital, etc.) are not allowed on the mining robot.
- 7) Global Positioning Satellite (GPS) or IMU-enabled GPS devices are not allowed. Teams have to explain to the judges how the device will be switched off or the data is subtracted and ensure the internal calculations do not make use of the GPS or IMU-enabled GPS device.

- 8) The mining robot may not pass beyond the confines of the outside wall of the mining arena and the collector bin during each competition attempt to avoid potential interference with the surrounding enclosure. The team must declare the robot orientation by length and width to the inspection judge. Because of actual Lunar hardware requirements, no surface ramps leading to the collector bin of any kind will be provided or allowed. An arrow on the reference point (the reference location and arrow pointing forward can be any point and direction of the team's choosing, except up) must mark the forward direction of the mining robot in the starting position configuration. The judges will use this reference point and arrow to orient the mining robot in the randomly selected direction and position (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). Multiple mining robot(s) systems are allowed but the total mass and starting dimensions of the whole system must comply with the volumetric dimensions given in this rule.

Autonomy

- 1) There will be at least three (3) boulder obstacles placed on top of the BP-1 surface within the obstacle area before each competition attempt is made. The placement of the boulder obstacles will be randomly selected before the start of the competition. Each obstacle will have a diameter of approximately 30 cm to 50 cm and will have random heights. There will be at least two (2) craters of varying depth and width, being no wider or deeper than 50 cm. No obstacles will be intentionally buried in the BP-1 by NASA, however, BP-1 includes naturally occurring rocks.
- 2) For a team to earn mining points in the autonomous category, the team cannot touch the controls during the autonomous period as defined in detail below. Orientation data cannot be transmitted to the mining robot in the autonomous period. Telemetry to monitor the health of the mining robot is allowed during the autonomous period.
- 3) The walls of the mining arena shall not be used for sensing by the robot to achieve autonomy. The team must explain to the inspection judges how their autonomous systems work and prove that the autonomy sensors do not use the walls. There are no walls on off-world locations and teams shall operate as closely as possible on that scenario of operations. Integrity is expected of all team members and their faculty advisors. Failure to divulge the method of autonomy sensing shall result in disqualification from the competition.
- 4) During each competition attempt, the mining robot is limited to autonomous and telerobotic operations only.
 - a) No physical access to the mining robot will be allowed during each competition attempt.
 - b) Arena team members are not allowed to point out obstacles/arena surface conditions to the Mission Control Center team members. In addition, telerobotic operators are only allowed to use data and video originating from the mining robot and the NASA video monitors.
 - c) Visual and auditory isolation of the telerobotic operators from the mining robot in the Mission

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

- d) No other outside communication via cell phones, radios, other team members, etc. is allowed in the Mission Control Center once each competition attempt begins. During the 5 minute setup period, a handheld radio link will be provided between the Mission Control Center team members and team members setting up the mining robot in the mining arena to facilitate voice communications during the setup phase only.
- e) Team operators are not permitted to update or alter the autonomy program to account / detect or upload information about obstacle locations.
- f) Teams are allowed to interact with an interface that allows different pieces of telemetry data to be viewed as long as there is no real time or other interaction to control or influence the robot. Teams must explain to the attending judge before each competition run how they are interacting with the telemetry system and the judge will observe to ensure compliance with all competition rules.

Communications / Wireless Systems

- 1) Each team is required to command and monitor their mining robot over the NASA provided network infrastructure.
- 2) This configuration must be used for teams to communicate with their robot.
- 3) The “Lander” camera is staged in the Mining Arena, and Lander Control Joystick and camera display will be located with the team in the Mission Control Center (MCC).
- 4) The MCC will have an official timing display. The excavated mass will be displayed after the end of the competition run.
- 5) Handheld radios will be provided to each team to link their Mission Control Center team members with their corresponding team members in the mining arena during setup.
- 6) Each team will provide the wireless link (access point, bridge, or wireless device) to their mining robot, which means that each team will bring their own Wi-Fi equipment/router and any required power conversion devices. Teams must set their own network IP addresses to enable communication between their mining robot and their control computers, through their own wireless link hosted in the Mining arena
 - a) In the mining arena, NASA will provide an elevated network drop (male RJ-45 Ethernet plug) that extends to the Mission Control Center, where NASA will provide a network switch for the teams to plug in their laptops.
 - b) The network drop in the Mining arena will be elevated high enough above the edge of the regolith bed wall to provide adequate radio frequency visibility of the Mining arena

- c) A shelf will be set up next to the network drop at a height 0 to .5 meter above the walls of the arena, and will be placed in a corner area on the same side as the collection bin. During robot system operations during the competition, there may be some dust accumulation in this area. This shelf is where teams will place their Wireless Access Point (WAP) to communicate with their mining robot.
 - d) Teams are strongly encouraged to develop a dust protection cover for their wireless access point (WAP) that does not interfere with the radiofrequency signal performance.
 - e) The WAP shelves for side A and side B of the Mining arena will be at least 6 meters apart to prevent electromagnetic interference (EMI) between the units.
- 7) Power Interfaces
- a) NASA will provide a standard US National Electrical Manufacturers Association (NEMA) 5-15 type, 110 VAC, 60 Hz electrical jack by the network drop. This will be no more than 1.5 meters from the shelf.
 - b) NASA will provide standard US NEMA 5-15 type, 110 VAC, 60 Hz electrical connections in the Mission Control Center for each team.
 - c) The team must provide any conversion devices needed to interface team access points or Mission Control Center computers or devices with the provided power sources.
- 8) During the setup phase, the teams will set up their access point and verify communication with their mining robot from the Mission Control Center.
- 9) The teams must use the USA IEEE 802.11b, 802.11g, or 802.11n standards for their wireless connection (WAP and rover client).
- a) Teams cannot use multiple channels for data transmission; meeting this rule will require a spectral mask or “maximum spectral bandwidth setting” of 20MHz for all 2.4 GHz transmission equipment.
 - b) Encryption is not required, but it is highly encouraged to prevent unexpected problems with team links.
 - c) During a match, one team will operate on channel 1 and the other team will operate on channel 11. See Figure 2. These channels will be monitored during the competition by NASA to assure there are no other teams transmitting on the assigned team frequency.
- 10) Teams must be able to use and switch between channel 1 and channel 11 for the competition.
- 11) Each team will be assigned an SSID that they must use for the wireless equipment for channel 1 and channel 11.
- a) SSID will be “Team_##.”

- b) Teams are required to broadcast their SSID.
- 12) The use of specific low power (these power consumers are not part of the total power consumed COTS meter) Bluetooth transmission equipment in the 2.4 GHz range is allowed for sensors and other robot communications. Bluetooth is allowed only at power levels of Classes 2, 3, and are limited to a maximum transmit power of 2.5 mW EIRP. Class 1 Bluetooth devices are not allowed.
- 13) The use of 2.4 GHz ZigBee technology is prohibited because of the possibility of interference with the competition wireless transmissions.
- 14) Technology that uses other ISM non-licensed radio frequencies outside of the 2.4 GHz range, such as 900 MHz and 5 GHz, are allowed to be used for any robot or sensor systems, but these frequencies will not be monitored during the competition. Interference avoidance will be the responsibility of the Team and will not be grounds for protest by any team.
- 15) Radio Frequency Power:
- a) All Team provided wireless equipment shall operate legally within the power requirements set by the FCC for Unlicensed Wireless equipment operating in the ISM radio band. The FCC Federal Regulations are specified in the Electronic Code of Federal Regulations, Title 47, Telecommunication, Part 15, and must be followed if any commercial equipment is modified. All unmodified commercial off the shelf access point equipment and computers already meet this requirement.
 - b) If a team inserts any type of power amplification device into the wireless transmission system, this will likely create a violation of FCC rules and this is NOT allowed in the competition.
 - c) This radio frequency power requirement applies to all wireless transmission devices at any ISM frequency.
- 16) Data Utilization Bandwidth Constraints
- a) Use of the NASA provided situational awareness camera in the control room will add 200 kb/s of data use for each camera. If the team elects to turn on the camera during the match, they will be charged for the full 200 kb/s of data use.
 - b) The communications link is required to have an average data utilization bandwidth of no more than 5,000 kb/s. There will not be a peak data utilization bandwidth limit.
- 17) For every kg of robot mass, a typical commercial lunar lander vendor will allow 10 kbps bandwidth. Higher bandwidth will result in additional mission costs. All teams are encouraged to stay within this bandwidth allocation and the judges will assess this metric as part of the Communications bandwidth prize.
- 18) Radio Frequencies and Communications Approval
- a) Each team must demonstrate to the communication judges that their mining robot and access

point are operating only on their assigned channel. Each team will have approximately 15 minutes at the communication judges' station.

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

Figure 1

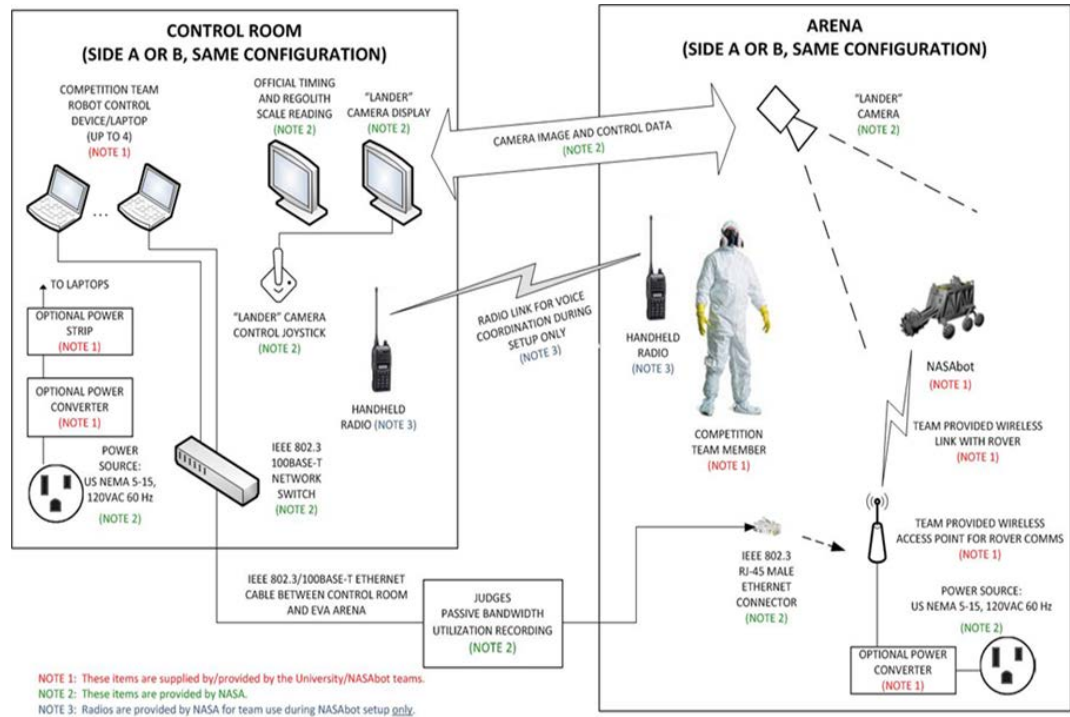
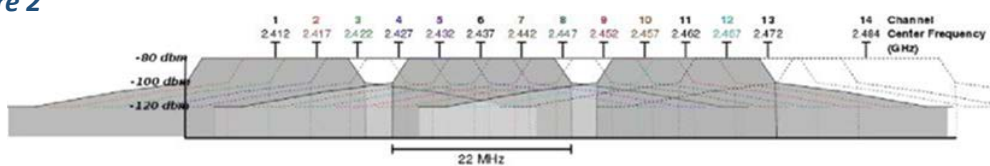


Figure 2



Non-Overlapping Channels for 2.4 GHz WLAN

802.11b (DSSS) channel width 22 MHz



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



Scoring

The teams with the first, second and third most mining points averaged from both attempts will receive 25, 20 and 15 points, respectively. Teams not winning first, second or third place in the mining category can earn one bonus point for each 0.5 kilogram of rock/gravel mined and deposited up to a maximum average of ten points. All decisions by the judges are final.

Exception for RMC: Lunabotics 2020 Only.

Teams may still compete if the robot fails the mass and dimensions inspection, the score assigned will be zero (0) mining points for the “Pass All Inspections (Comm/Vehicle)” Mining Category Element. The robot must pass all other inspections (ex: safety, communications, etc.) to compete in the arena.

Sample Mining Points Calculator				
Mining Category Elements	Units	Specific Points	Actuals	Mining Points
Pass All Inspections (Comm/Vehicle).	1,000=Pass / 0=Fail	0 or 1,000	1,000.00	1000.00
Gravel Mined - The rock/gravel will be sieved out at the collector bin and weighed separately from the BP-1. During each competition attempt, the team will earn 15 mining points for each kilogram in excess of 1.0 kg of rock/gravel (ex: 11 kg of gravel mined will earn 150 mining points).	kg	15.00	11.00	150.00
Average Data Bandwidth Use - During each competition attempt, the team will lose one (1) mining point for each 50 kilobits/second (kb/s) of average data used (-1/50kb/sec).	Kbps/sec	-0.02	1066.00	-21.32
Camera bandwidth Use - During each competition attempt, the team will lose 200 kb/s of data for each situational awareness camera used (camera bandwidth usage 200 kb/camera).	Kpbs/camera	-200.00	400.00	-8.00

Mining Robot Mass - During each competition attempt, the team will lose 8 Mining points for each kilogram of total mining robot mass. (For example, a mining robot that weighs 60 kg will lose 480 Mining points)(-8/kg).	kg	-8.00	60.00	-480.00
Report Energy Consumed - During each competition attempt, the team will lose one (1) Mining point for each watt-hour of energy consumed. The electrical energy consumed must be displayed by an (commercial off the shelf or “COTS”) electronic data logger and verified by a judge (-1/watt-hour).	watt-hour	-1.00	9.00	-9.00
Dust Tolerant Design - Based on judge's decision, 3 items (30 points max).	Judge's Decision (JD)	0 to 30.00	30.00	30.00
Dust Free Operation - Based on judge's decision, 3 items (70 points max).	Judge's Decision (JD)	0 to 70.00	70.00	70.00
Autonomy - See rubric.		50, 150, 300 or 500	150.00	150.00
Total Points				881.68

- 1) Mining: Scoring for the Mining Category will require teams to consider a number of design and operation factors such as high robot dust tolerance and minimizing dust projection, efficient communications, minimizing vehicle mass, minimize energy/power required, and maximize autonomy. In each of the two official competition attempts, the teams will score cumulative mining points.

See “Sample Mining Points Calculator” above; the teams’ mining points will be the average of their two competition attempts.

- a) Each team will earn 1000 Mining points after passing the safety inspection and communications check.
- b) During each competition attempt, the team will earn 15 Mining points for each kilogram in excess of 1.0 kg of rock/gravel deposited in the collector bin. (For example, 11 kg of gravel mined will earn 150 Mining points.) The rock/gravel will be sieved out at the collector bin and weighed separately from the BP-1.

- c) During each competition attempt, the team will lose one (1) mining point for each 50 kilobits/second (kb/s) of average data used.
 - d) During each competition attempt, the team will lose 200 kb/s of data for each situational awareness camera used (Camera Bandwidth Usage 200 kb/camera)
 - e) During each competition attempt, the team will lose 8 Mining points for each kilogram of total mining robot mass. (For example, a mining robot that weighs 60 kg will lose 40 Mining points).
 - f) During each competition attempt, the team will lose one (1) Mining point for each watt-hour of energy consumed. The electrical energy consumed must be displayed by an (commercial off the shelf or “COTS”) electronic data logger and verified by a judge.
 - g) During each competition attempt a team can earn up to 30 Mining points for dust tolerant design features on the mining robot. The judges will allocate these points based on an inspection.
 - h) During each competition attempt a team can earn up to 70 Mining Points for dust free operation. The judges will allocate these points based on actual performance during the competition attempts. (If the mining robot has exposed mechanisms where dust could accumulate during a lunar mission and degrade the performance or lifetime of the mechanisms, then fewer Mining points will be earned in this category. If the mining robot raises a substantial amount of airborne dust or projects it due to its operations, fewer mining points will be earned. Ideally, the mining robot will operate in a clean manner without dust projection, and all mechanisms and moving parts will be protected from dust intrusion. The mining robot will not be penalized for airborne dust while dumping into the collector bin. All decisions by the judges regarding dust tolerance and dust projection are final.)
 - i) DUST-TOLERANT DESIGN - The 30 points for dust-tolerant design will be broken down as follows:
 - Drive train and components enclosed/protected 10 points
 - Custom dust sealing features (bellows, seals, etc.) 10 points
 - Active dust control (brushing, electrostatics, etc.) 10 points
 - j) DUST-FREE OPERATION - The 70 points for dust-free operation will be broken down as follows:
 - Driving without dusting up crushed basalt 20 points
 - Digging without dusting up crushed basalt 30 points
 - Transferring crushed basalt without dumping the crushed basalt on your own Robot 20 points
- 2) Autonomous Operation: During each competition attempt, the team will earn up to 500 Mining points for autonomous operation. As Mission Control Judges (MCJs) are not intimately familiar with each robot’s concept of operations (ConOps) procedures, it is the sole responsibility of the team members in the control room to coordinate with and inform the MCJs of each attempt for autonomy points in order to make sure their autonomous attempts are recognized and therefore

scored correctly. Mining points will be awarded for successfully completing the following activities autonomously:

a) Excavation Automation: 50 pts

- Teams are allowed to traverse to the Mining Arena via remote control.
- Once in the Mining Arena they need to indicate to the MCJ that they are going hands free for the excavation attempt.
- The robot must execute all machine control commands itself during the excavation task.
- The robot must demonstrate the ability to dig through the upper layers of regolith and reach the icy regolith gravel. Hands free operation must begin before the robot engages the regolith to begin the excavation process. Excavation mechanisms must be completely removed from the regolith and from the excavation hole before returning to remote-control operation. Icy regolith gravel must be deposited in the robot for transport back to the hopper per the robot's design. Icy regolith gravel deposit in the robot will be at the MCJ judgement. (The intent is to show that the robot can dig down to the icy regolith and be successful in bringing up some icy regolith with completely hands-free operation). MCJ may engage the arena judges for confirmation if camera angle/performance does not allow confirmation in Mission Control.
- Once excavation is complete the team must indicate they are going to remote control before taking control.
- This level of automation will require teams to master the lower level machine control of their robot platform associated with excavation. It is noted that past teams have proven this capability to be helpful in achieving better mining results, as the coordination of the robot for excavation can be difficult to master.

b) Dump Automation: 50 pts

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

c) Travel Automation: 150 pts

- Teams may begin in remote-control and move the robot within the starting zone only in order to lock in their localization solution. The teams must then indicate to the MCJ that they are going into hands free mode while still in the starting zone. The robot must remain in hands free mode while crossing the obstacle field and crossing into the mining arena. The robot must start in the starting zone and remain hands free until any part of the robot has crossed into the mining zone (as determined by the MCJ) This level of automation will require the team to master the following:
- Localization across the entire competition arena
- Object detection and location relative to the robot
- Navigational planning based on location and obstacles/traversable area
- The competition will attempt to construct the obstacle field in such a way as to require obstacle detection and mapping in order to plan an appropriate route to reach the mining arena. “Point and traverse” in a straight line will not be possible due to crater and boulder obstacles.
- If attempting excavation automation in coordination with travel automation the robot must remain in “hands free” control during travel and excavation.

d) Full Autonomy (One cycle): 300 pts

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

e) Full Autonomy –500 pts

- The robot must be in hands free control for all 15 minutes of the competition run completing 2 or more cycles of depositing icy regolith. The minimum requirement of 1 kg of icy regolith must be achieved to be awarded this autonomy point level.
- This level requires mastery of all aspects of autonomy associated with this competition and demonstrates a level of robustness to complete at least 2 full cycles. System robustness is essential for terrestrial and extra-terrestrial mining.
- Any three successful completions of the Excavation, Dump, and Travel attempts will be combined for scoring. These could occur over separate passes within the 15 minute run. Points will only count for one successful completion – i.e. you can only get 50 points for excavation automation even if you use it for every pass of the run. Combining all three in one pass is the Fully Autonomous – One Cycle level

of 300 points. See the Table below for examples of potential point opportunity in the autonomy category.

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

VII. GLOSSARY OF TERMS

Accreditation Board for Engineering and Technology (<http://www.abet.org>):

The Competition rules and rubrics meets the ABET requirements for engineering and engineering technology accreditation.

Astronaut Memorial Foundation's Center for Space Education (CSE): located adjacent to the north-west end of the Kennedy Space Center Visitor Complex (KSCVC) at the eastern terminus of Florida S.R. 405 in Bldg. M6-306.

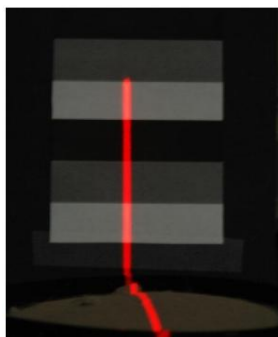
Autonomous: The operation of a mining robot with no human interaction.

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

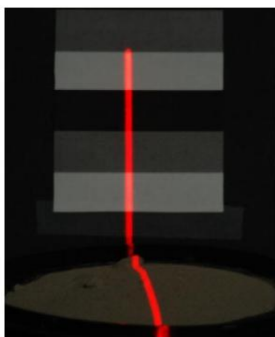
http://www.lpi.usra.edu/publications/books/lunar_sourcebook/

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

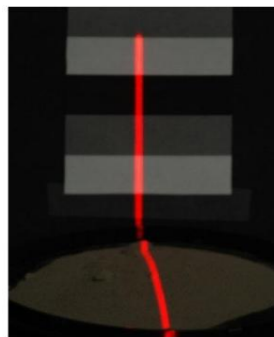
10 Degree



16 Degree



21 Degree



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

- It does not behave like sand.
- The coefficient of friction has not been measured.
- There are naturally occurring rocks in the aggregate.
- BP-1 is made from crushed basalt fines and not commercially available.

- See “Soil Test Apparatus for Lunar Surfaces” <http://www.nasa.gov/nasarmc>
- The density of the compacted BP-1 aggregate will be between 1.5 g/cm³ and 1.8 g/cm³.
- BP-1 behaves like a silty powder soil with most particles are under 100 microns in diameter.
- “Planetary Simulant Database: BP-1 Black Point”, https://sciences.ucf.edu/class/simulant_bp1/
- “Preliminary Geological Findings on the BP-1 Simulant” is located at https://www.nasa.gov/sites/default/files/atoms/files/nasa_tm_2010_216444.pdf
- Will be compacted and the top layer will be raked to a fluffy condition of approximately .75 g/cm³, similar to the Lunar surface.
- Teams are encouraged to develop or procure simulants based on basaltic minerals and lunar surface regolith particle size, shape, and distribution.
- Philip Metzger from University of Central Florida giving a talk "Material Properties of Regolith and Other Materials Available on the Moon, Mars and Asteroids for 3D Additive Construction" on August 24, 2015 at Caltech <https://www.youtube.com/watch?v=npdTVOYB8d4>

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

Competition attempt: The operation of a team's mining robot intended to meet all the requirements for winning the mining category by performing the functional task. The duration of each competition attempt is 10 minutes.

Excavated mass: Mass of the excavated BP-1 and/or rock/gravel deposited to the collector bin by the team's mining robot during each competition attempt, measured in kilograms (kg) with official result recorded to the nearest one tenth of a kilogram (0.1 kg).

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

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

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

Mining arena: Located in the Astronaut Memorial Foundation's Center for Space Education (CSE), is an open-topped container, each arena measures ~5.4 m X ~3.6 m and is filled to a depth of ~45 cm with BP-1. The mining zone contains ~30 cm of BP-1 over a ~15 cm bed of gravel (icy regolith simulant), with a mean particle size diameter of ~ 2 cm. This is where the mining robot will perform each competition attempt.

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

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

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

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

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

Rock/Gravel: Intended to simulate icy-regolith buried in the South Polar region of the Moon. The gravel will be ~2 cm in diameter (minimum size) but will have random particle sizes larger than that also mixed into the gravel. The rock/gravel may be mixed in with the BP-1 in small quantities, but the majority of the gravel will be on the approximately lower 30 cm of the mining area regolith depth only. The gravel will be made of a hard rock material, and will not have a specific color.

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

Time Limit – 5 minutes to set up the mining robot in the mining arena and 15 minutes for the mining robot to perform the functional task per run and 5 minutes to remove the robot from the arena.

// end of rules and rubrics //