NASA's Fourth Annual Lunabotics Mining Competition

Rules & Rubrics 2013

Kennedy Space Center Visitor Complex

Kennedy Space Center, Florida

Introduction

NASA's Lunabotics Mining Competition is designed to promote interest in space and STEM (the fields of science, technology, engineering, and mathematics). The competition uses excavation, a necessary first step toward extracting resources from the regolith and building bases on the moon. The unique physical properties of lunar regolith and the reduced, 1/6 gravity, vacuum environment make excavation a difficult technical challenge. Advances in lunar-regolith mining could contribute significantly to our nation's space vision and to NASA's exploration of space.

The competition will be conducted by NASA at the Kennedy Space Center Visitor Complex. The team that can use telerobotic or autonomous operation to excavate lunar-regolith simulant, called Black Point-1 or BP-1, and score the most points wins the Joe Kosmo Award for Excellence trophy, KSC launch invitations, team certificates for each member, and a $5,000 team scholarship. Awards for other categories include monetary team scholarships, a school trophy or plaque, team and individual certificates, and KSC launch invitations.

Undergraduate and graduate student teams enrolled in a U.S. or international college or university are eligible to enter NASA's Lunabotics Mining Competition. Design teams must include at least one college or university faculty member and at least two undergraduate or graduate students. There are no other limits on team size. A team should have enough members to successfully operate their Lunabot. Teams will compete in up to five major competition categories: onsite mining, systems engineering paper, outreach project, slide presentation (optional), and team spirit (optional). In addition, teams can earn bonus points for mined and deposited BP-1 in the competition attempts, having multidisciplinary teams, and collaborating between a majority institution and a U.S. minority-serving institution. All documents must be submitted in English. International teams are highly encouraged to have their submissions edited, specifically to reduce grammatical errors.

The Lunabotics Mining Competition is a student competition that will be conducted in a positive, professional way. This is a reminder to be courteous in all your correspondence and all interactions at the competition. Unprofessional behavior or unsportsmanlike conduct will not be tolerated and will be grounds for disqualification. The frequently-asked-question (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 NASA's Fourth Annual Lunabotics Mining Competition Rules and Rubrics; stay updated with new FAQs; communicate with NASA's representatives; and complete all surveys. These rules and rubrics are subject to future updates by NASA at its sole discretion.

For more information, visit NASA's Lunabotics Mining Competition on the Web at www.nasa.gov/Lunabotics, on Facebook at www.facebook.com/Lunabotics, and on YouTube at http://www.youtube.com/user/Lunabotics; and follow Lunabotics on Twitter at http://twitter.com/#!/NASALunabotics.

Lunabotics Onsite Mining Category

The scoring for the Mining Category will not be based primarily on the amount of material excavated in the allowed time but instead will require teams to consider a number of design and operation factors, such as dust tolerance and projection, communications, vehicle mass, energy/power required, and level of autonomy. Each team must compete onsite at the Kennedy Space Center Visitor Complex, Florida, in the United States of America, on May 20–24, 2013. To qualify to win in this category, a team must mine and deposit at least 10 kg of BP-1 during either of two competition attempts. If the minimum amount of 10 kg of BP-1 is not met for an attempt, then the total LunaPoints score for that attempt will be 0. In the case of a LunaPoints tie, the teams will compete in a tie-breaking competition attempt. The judges' decisions are final in all disputes. The teams with the first, second, and third most LunaPoints averaged from both attempts will receive team plaques; individual team certificates; KSC launch invitations; $3,000, $2,000, and $1,000 scholarships; and 30, 25, and 20 points toward the Joe Kosmo Award for Excellence, respectively. Teams not winning first, second, or third place in the Mining Category can earn 1 bonus point for each kilogram of BP-1 mined and deposited, up to a maximum average of 10 points toward the Joe Kosmo Award for Excellence. The most innovative and lunarlike design will receive the Judges' Innovation Award at the discretion of the mining judges.

1) Teams must arrive at the Lunabotics Mining Competition Check-In Tent in Parking Lot 4 of the Kennedy Space Center Visitor Complex no later than 3:00 p.m. on Monday, May 20, 2013; but teams are encouraged to arrive earlier.

Game Play Rules

2) Teams will be required to perform two official competition attempts using BP-1 in the LunArena provided by NASA. NASA will fill the LunArena with compacted BP-1 that matches lunar regolith as closely as possible. NASA will randomly place three obstacles and create two craters on each side of the LunArena. Each competition attempt will occur with two teams competing at the same time, one on each side of the LunArena. See Diagrams 1 and 2. NASA will choose the order of teams for the competition attempts.

3) In each of the two official competition attempts, the teams will score cumulative LunaPoints. See Table 1 for the Mining Category Scoring Example. The teams' ranking LunaPoints will be the average of their two competition attempts.

   A) Each team will be awarded 1000 LunaPoints after passing the safety inspection and communications check.

   B) During each competition attempt, the team will earn 3 LunaPoints for each kilogram of BP-1 in excess of 10 kg deposited in the LunaBin. (For example, 110 kg of BP-1 mined will earn 300 points.)

   C) During each competition attempt, the team will lose 1 LunaPoint for each 50 kilobits/second (kb/sec) of average data used throughout each competition attempt.

   D) During each competition attempt, the team will lose 8 LunaPoints for each kilogram of total Lunabot mass. (For example, a Lunabot that weighs 80 kg will lose 640 LunaPoints.)

   E) During each competition attempt, the team will earn 20 LunaPoints if the amount of energy consumed by the Lunabot during the competition attempt is reported to the judges after each attempt. The amount of energy consumed will not be used for scoring; a team must only provide a legitimate method of measuring the energy consumed and be able to explain the method to the judges.

   F) During each competition attempt, the judges will award the team 0 to 100 LunaPoints for regolith-dust-tolerant design features on the Lunabot (up to 30 LunaPoints) and regolith-dust-free operation (up to 70 points). If the Lunabot has exposed mechanisms where dust could accumulate during a lunar mission and degrade the performance or lifetime of the mechanisms, then fewer points will be awarded in this category. If the Lunabot raises or projects a substantial amount of airborne dust, then fewer points will be awarded. Ideally, the Lunabot will operate in a clean manner without dust projection, and all mechanisms and moving parts will be protected from dust intrusion. The Lunabot will not be penalized for airborne dust while dumping into the LunaBin. All decisions by the judges regarding dust tolerance and dust projection are final.

G) During each competition attempt, the team will earn 500 LunaPoints if full autonomy is achieved. To achieve full autonomy, teams cannot touch the controls once the 10-minute competition attempt begins, except to send start and stop commands. If you touch the controls, then you are no longer eligible for the autonomy points for that competition attempt; however, teams may revert to manual control to complete that competition attempt. Telemetry to monitor the health of the Lunabot is allowed during autonomous operations.

Table 1: Mining Category Scoring Example

Mining Category Elements	Specific Points	Actual	Units	LunaPoints
Pass Inspections				1000
Regolith over 10 kg	+3/kg	110	kg	+300
Average Bandwidth	–1/50kb/sec	5000	kb/sec	–100
Lunabot Mass	–8/kg	80	kg	–640
Report Energy Consumed	+20	1	1= Achieved 0= Not Achieved	+20
Dust-Tolerant Design (30%) & Dust-Free Operation (70%)	0 to +100	70	Judges' Decision	+70
Full Autonomy	500	1	1= Achieved 0= Not Achieved	+500
Total				1150

4) All excavated mass deposited in the LunaBin during each official competition attempt will be weighed after the completion of each competition attempt.

5) At the start of each competition attempt, the Lunabot will be placed in the randomly selected starting positions. The Lunabot may not occupy any location outside the defined starting position in the LunArena. See Diagrams 1 and 2.

6) A team's Lunabot will only excavate BP-1 located in that team's respective mining area at the opposite end of the LunArena from the team's starting area. The team's starting direction will be randomly selected immediately before the competition attempt. Mining is allowed as soon as the mining line is crossed.

7) The Lunabot is required to move across the obstacle area to the mining area and then move back to the LunaBin to deposit the BP-1 into the LunaBin. See Diagrams 1 and 2.

8) Each team is responsible for placement of their Lunabot onto and removal of it from the BP-1 surface. There must be one person per 23 kg of mass of the Lunabot, requiring four people to carry the maximum allowed mass. Assistance will be provided if needed.

9) Once the Lunabot is placed in the LunArena, each team is allotted a maximum of 10 minutes to power on and establish communication with their mission control, 10 minutes for the competition attempt, and then 5 minutes to remove the Lunabot from the LunArena.

10) The Lunabot operates during the 10-minute limit of each competition attempt. The competition attempts for both teams in the LunArena will begin and end at the same time. Only student team members may control the Lunabot during the official competition attempt.

11) The Lunabot will end operation immediately when the power-off command is sent, as instructed by the competition judges.

12) The Lunabot cannot be anchored to the BP-1 surface before the beginning of each competition attempt.

13) The Lunabot will be inspected during the practice days and right before each competition attempt. Teams will be permitted to repair or otherwise modify their Lunabots any time before their official inspection for each attempt.

Field Rules

14) The top edge of the LunaBin will be placed so that it is next to the side walls of the LunArena, without a gap, and the height will be approximately 0.5 meter from the top of the BP-1 surface directly below it. The top opening of the LunaBin will be 1.65 meters long and 0.48 meters wide. See Diagrams 1 through 3.

15) Targets or beacons may be attached to the LunaBin for navigation purposes only, but cannot be placed on the excavating end of the LunArena. This navigational aid system must be attached during the setup time and removed during the removal time. If a navigational aid system is attached to the LunaBin, it must not exceed the width of the LunaBin and it must not weigh over 9 kg. The navigational aid system must be self-powered and its mass will be included in the Lunabot mass limit of 80.0 kg. The target/beacon may send a signal or light beam, but for safety reasons, only ANSI Z136, Class II, 2 or 2M lasers will be allowed. The judges will inspect all laser devices and verify that they comply with the ANSI Z136, Class II, 2 or 2M standard and that they have not been modified (for optics or power). Original supporting documentation from the laser instrumentation vendor must be given to the inspection judge. Navigational aids may be deployed from the Lunabot after the official start time of the competition attempt. Navigational aids must comply with all RF constraints as stated in rule 23.

16) There will be three obstacles placed on top of the compressed BP-1 surface within the obstacle area before each competition attempt is made. The placement of the obstacles will be randomly selected before the start of the competition. Each obstacle will have a diameter of approximately 20 to 30 cm and an approximate mass of 7 to 10 kg. There will be two craters of varying depth and width, no wider or deeper than 30 cm. No obstacles will be intentionally buried in the BP-1 by NASA; however, BP-1 contains naturally occurring rocks. After each competition attempt, the obstacles will be removed, the BP-1 will be returned to a compacted state, if necessary, and the obstacles and craters will be returned to the LunArena.

17) The Lunabot must operate within the LunArena: it is not permitted to pass beyond the confines of the outside wall of the LunArena and the LunaBin during each competition attempt. The BP-1 regolith will not be filled to the brim of the LunArena—the walls will be visible. The walls will have no special markings. The BP-1 aggregate will be less than 1 meter deep. The sandbox itself is 1 meter high and will have enough of a border to safely contain the excavators. The BP-1 must be mined in the mining area and deposited in the LunaBin. A team that excavates any BP-1 from the starting or obstacle areas will be disqualified. The BP-1 must be carried from the mining area to the LunaBin by any means and be deposited in the LunaBin in its raw state. A secondary container, such as a bag or box, may not be deposited inside the LunaBin. Depositing a container in the LunaBin will result in disqualification of the team. The Lunabot can separate intentionally, if desired, but all parts of the Lunabot must be under the team's control at all times. Any ramming of the wall may result in a safety disqualification. The walls may be used for the purposes of mapping autonomous navigation and avoiding collision. A wall may be touched or it may be brushed by a switch sensor spring wire to avoid collision.

18) The Lunabot must not use the wall as support or push/scoop BP-1 up against the wall to accumulate BP-1. If the Lunabot exposes the LunArena bottom, it may contact the bottom but must not use the bottom for support. Teams should be prepared for airborne dust raised by either team during each competition attempt.

Technical Rules

19) During each competition attempt, the Lunabot is limited to autonomous and telerobotic operations only. No physical access to the Lunabot will be allowed during each competition attempt. In addition, telerobotic operators are allowed to use only data and video originating from the Lunabot and the NASA video monitors. During each competition attempt, the telerobotic operators must remain in the Mission Control Center and be visually and auditorially isolated from the Lunabot. Telerobotic operators will be able to observe the LunArena through overhead cameras in the LunArena via monitors that will be provided by NASA in the Mission Control Center. These color monitors should be used for situational awareness only. 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 10-minute setup period, a handheld radio link will be provided for voice communications between the Control Room team members and team members setting up the Lunabot in the LunArena.

20) The Lunabot mass is limited to 80.0 kg. Subsystems on the Lunabot used to transmit commands/data and video to the telerobotic operators are counted toward the 80.0 kg mass limit. Equipment not on the Lunabot used to receive data from and send commands to the Lunabot for telerobotic operations is excluded from the 80.0 kg mass limit.

21) No facility power will be provided to the Lunabot. There are no power limitations except that the Lunabot be self-powered and that the power source be included in the Lunabot mass limit of 80.0 kg.

22) The Lunabot must be equipped with an easily accessible red emergency stop button (kill switch) of minimum diameter of 40 mm on the surface of the Lunabot and requiring no steps to access. The emergency stop button must stop the Lunabot's motion and disable all power to the Lunabot 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. The LunArena judges will push the emergency stop button if an unsafe event occurs. A closed control signal to a mechanical relay is allowed as long as it stays open to disable the Lunabot. The reason for this rule is to completely safe the Lunabot 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 subsystems as well. Laptop computers may stay powered on.

23) The communications rules for telerobotic operations follow.

A. LUNABOT WIRELESS LINK

1. Each team is required to command and monitor their Lunabot over the NASA-provided network infrastructure. Figure 1 shows
   a. the configuration provided to teams to communicate with their Lunabot,
   b. the "Lunar Lander" camera staged in the LunArena, and Lunar Lander Control Joystick provided to the team in the Control Room,
   c. the official timing display, which includes a real-time display of regolith collected during the match, and
   d. the handheld radios that will be provided to each team to link their Control Room team members with their corresponding team members in the LunArena during setup.

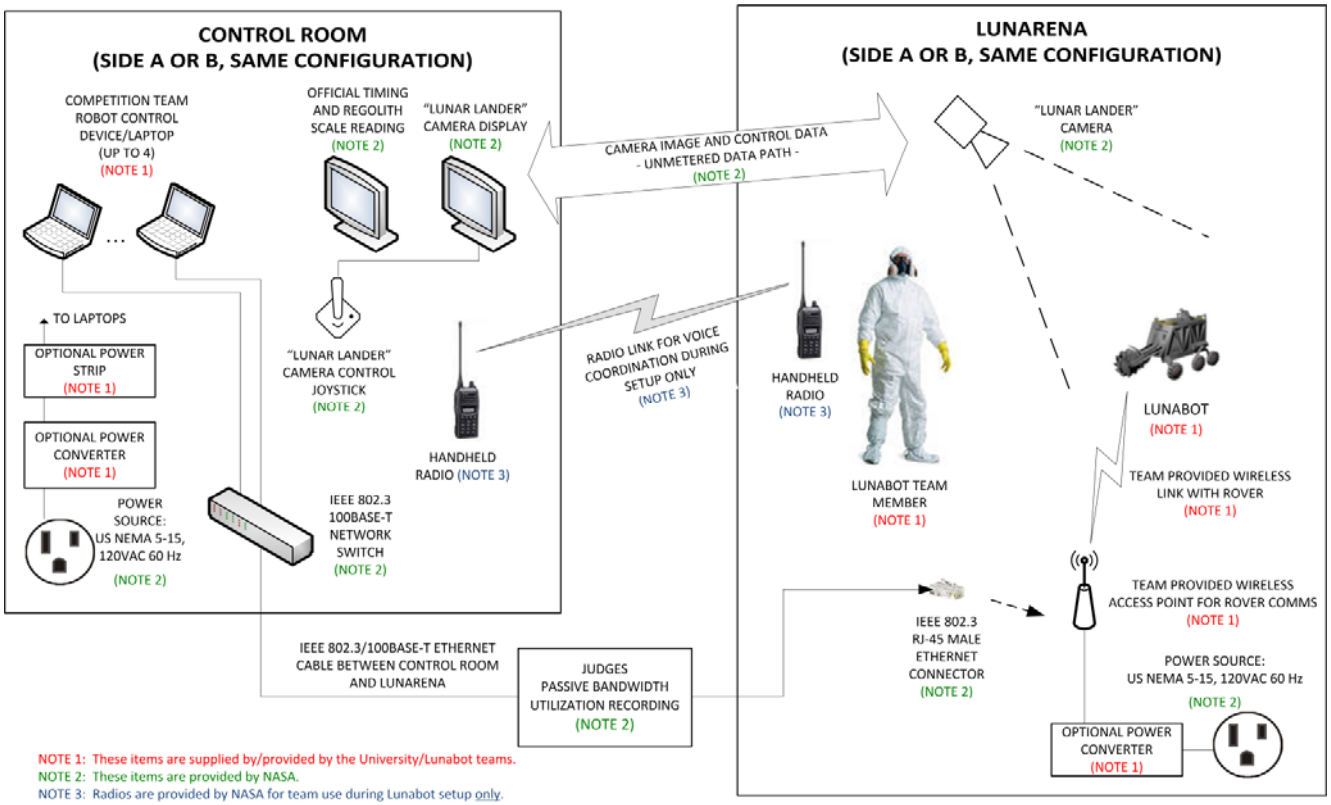

Figure 1

2. Each team will provide the wireless link (access point, bridge, or wireless device) to their Lunabot, 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 Lunabot and their control computers, through their own wireless link hosted in the LunArena.
    a. In the LunArena, NASA will provide an elevated network drop (female RJ-45 Ethernet jack) that extends to the Mission Control Center, where NASA will provide a network switch for the teams to plug in their laptops.
        i. The network drop in the LunArena will be elevated high enough above the edge of the regolith bed wall to provide adequate radio frequency visibility of the LunArena.
        ii. A shelf will be set up next to the network drop, will be 4 to 6 feet off the ground, and will be no more than 50 feet from the Lunabot. This shelf is where teams will place their Wireless Access Point (WAP) to communicate with their Lunabot. The LunArena will be 150 to 200 feet from the Mission Control Center.
        iii. The WAP shelves for side A and side B of the LunArena will be at least 25 feet apart to prevent electromagnetic interference (EMI) between the units.
    b. Power interfaces:
        i. NASA will provide a standard US National Electrical Manufacturers Association (NEMA) 5-15 type, 110 VAC, 60 Hz electrical jack by the network drop. Both will be no more than 5 feet from the shelf.
        ii. NASA will provide a standard US NEMA 5-15 type, 110 VAC, 60 Hz electrical jack in the Control Room for each team.
        iii. The team must provide any international conversion devices needed to interface team access points or Control Room computers or devices with the provided power sources.
    c. During the setup phase, the teams will set up their access point and verify communication with their Lunabot from the Control Room.
3. The teams must use the USA IEEE 802.11 b/g standard for their wireless connection (WAP and rover client). Teams cannot use multiple channels for data transmission. Encryption is not required, but it is highly encouraged to prevent unexpected problems with team links.
    a. During a match, one team will operate on channel 1 and the other team will operate on channel 11.
    b. Channels will be assigned when the teams check in with the LunaPit crew chief.
    c. If intersystem communications of equipment is required in the field, the team shall use the 2.4 GHz 802.11b/g channel that they are assigned for the event. This local intersystem communication on the field will not be counted in the average bandwidth measurement since this data would not be going through an Earth data link. Bluetooth equipment is not allowed on the Lunabot or in the LunArena.
4. Each team will be assigned an SSID that they must use for their wireless equipment.
    a. SSID will be “Team_##.”
    b. Teams will broadcast their SSID.
5. Bandwidth constraints:
    a. A team will be awarded the Efficient Use of Communications Power Award for using the lowest average bandwidth during the timed and NASA-monitored portion of the competition. Teams must collect the minimum 10 kg of BP-1 to qualify for this award.
    b. The communications link is required to have an <u>average</u> bandwidth of no more than 5 megabits per second. There will not be a <u>peak</u> bandwidth limit.

B. RF & COMMUNICATIONS APPROVAL

1. Each team must demonstrate to the communication judges that their Lunabot and access point are operating only on their assigned channel. Each team will have approximately 15 minutes at the communication judges’ station. The communication approval is required prior to any practice or competition attempts. The communication approval must be complete by 5:00 p.m. on Tuesday, May 21, 2013.
2. To successfully pass the communication judges’ station, a team must drive their Lunabot by commanding it from their Lunabot 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. If a fully autonomous Lunabot is constructed that does not emit any RF, the team will still need to demonstrate this configuration during the communication test. The team must demonstrate that their

system can move autonomously, and without using RF transmissions. If the autonomous Lunabot does emit RF, it must be constrained to the 802.11b/g channel that is assigned to the team.

3. If a team cannot demonstrate the above tasks in the allotted time, the team will be disqualified from the competition.
4. On Monday, May 20, 2013, on a first-come, first-serve basis, the LunaPit crew chief will assign each team a time to show the communication judges their compliance with the rules.
5. The NASA communications technical experts will be available to help teams make sure that they are ready for the communication judges' station on Monday, May 20, 2013, and Tuesday, May 21, 2013.
6. Once the team arrives at the communication judges' station, the team can no longer receive assistance from the NASA communications technical experts.
7. If a team is on the wrong channel during their competition attempts, the team will be disqualified and required to power down.

C. WIRELESS DEVICE OPERATION IN THE PITS

1. Teams will not be allowed to power up their transmitters on any frequency in the LunaPits during the practice matches or competition attempts. All teams must have a hard-wired connection for testing in the LunaPits.
2. Teams will have designated times to power up their transmitters when no practice or competition matches are underway.

24) The Lunabot must be contained within 1.5 m length × 0.75 m width × 0.75 m height. The Lunabot may deploy or expand beyond the 1.5 m × 0.75 m footprint after the start of each competition attempt but may not exceed a 1.5 m height. To avoid potential interference with the surrounding tent, the Lunabot may not pass beyond the confines of the outside wall of the LunArena and the LunaBin during each competition attempt. The team must declare the orientation of length and width to the inspection judge. Because of actual lunar-hardware requirements, no ramps of any kind will be provided or allowed. An arrow on the reference point must mark the forward direction of the Lunabot in the starting position configuration. The judges will use this reference point and arrow to orient the Lunabot in the randomly selected direction and position. A multiple-robot system is allowed, but the total mass and starting dimensions of the whole system must comply with the volumetric dimensions given in this rule.

25) To ensure that the Lunabot is usable for an actual lunar mission, the Lunabot cannot employ any fundamental physical processes (e.g., suction or water cooling in the open lunar environment), gases, fluids, or consumables that would not work in the lunar 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 Lunabot are included in the mass of the Lunabot. Pneumatic mining systems are allowed only if the gas is supplied by the Lunabot itself.

26) Components (i.e., electronic and mechanical) are not required to be space-qualified for the lunar vacuum, electromagnetic, or thermal environments. Since budgets are limited, the competition rules are intended to require Lunabots to show lunar-plausible system functionality, but the components do not have to be traceable to a space-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; proximity detectors; and Hall Effect sensors. Proceed at your own risk with sensors 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-cell or closed-cell foam, ultrasonic proximity sensors, or hydraulics.

27) The Lunabot may not use any process that causes the physical or chemical properties of the BP-1 to be changed or that otherwise disrupts the uniformity between competition attempts.

28) The Lunabot may not penetrate the BP-1 surface with more force than the weight of the Lunabot before the start of each competition attempt.

29) No ordnance, projectile, far-reaching mechanism (adhering to rule 24), etc., may be used. The Lunabot must move on the BP-1 surface.

30) No team can intentionally harm another team's Lunabot. This includes radio jamming, denial of service to network, BP-1 manipulation, ramming, flipping, pinning, conveyance of current, or other forms of 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 Lunabot as determined by the judges will be cause for immediate disqualification. A judge may disable the Lunabot by pushing the red emergency stop button at any time.

31) Teams must electronically submit documentation containing a description of their Lunabot, its operation, potential safety hazards, a diagram, and basic parts list by April 30, 2013, at 12:00 p.m. (noon), eastern time in the United States.

32) Teams must electronically submit via e-mail to Susan.G.Sawyer@nasa.gov a **link** to their YouTube video documenting no less than 30 seconds but no more than 5 minutes of their Lunabot in operation for at least one full cycle of operation by April 30, 2013, at 12:00 p.m. (noon), eastern time in the United States. One full cycle of operations includes excavating and depositing material. This video documentation is solely for technical evaluation of the Lunabot.

Shipping

33) **Plan ahead for shipping your Lunabot and its batteries because some batteries may not be allowed onboard airplanes or in shipping containers. A completed bill of lading and commercial invoice (for international shipments) with your shipping company to and from the competition must be submitted via e-mail to Susan.G.Sawyer@nasa.gov by April 30, 2013.** Teams may ship their Lunabots to **arrive no earlier than May 13, 2013**. The Lunabots will be held in a safe area without air conditioning and be placed in each team's LunaPit by Monday, May 20, 2013. The **ship-to** address is:

Transportation Officer, NASA
Central Supply, Bldg. M6-744
Kennedy Space Center, FL 32899
M/F: KSC Visitor Complex, Lunabotics Mining Competition, M/C: DNPS

Note: Do not have the shipping company deliver the Lunabot directly to the Kennedy Space Center Visitor Complex. They do not have facilities to store them until the LunaPits are set up. The shipper will come to the Pass & ID facility right before the gate on State Road 405. Central Receiving will send an escort.

34) Return shipping arrangements must be made prior to the competition. All Lunabots must be picked up from the Kennedy Space Center Visitor Complex **no later than 5:00 p.m. on Wednesday, May 29, 2013**. Any abandoned Lunabots will be discarded after this date. The **return** shipping address is:

Kennedy Space Center Visitor Complex
Lunabotics Shipping Area
Mail Code: DNPS
State Road 405
Kennedy Space Center, FL 32899

LunArena Diagrams

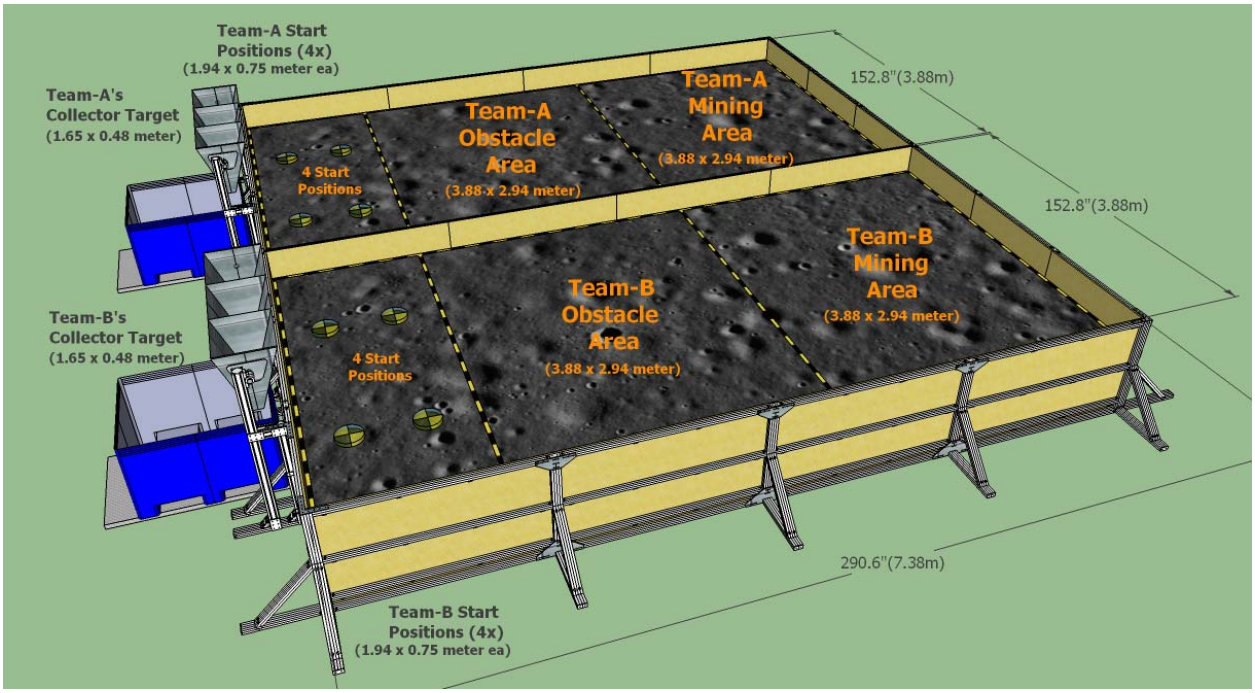

Diagram 1: LunArena (isometric view)

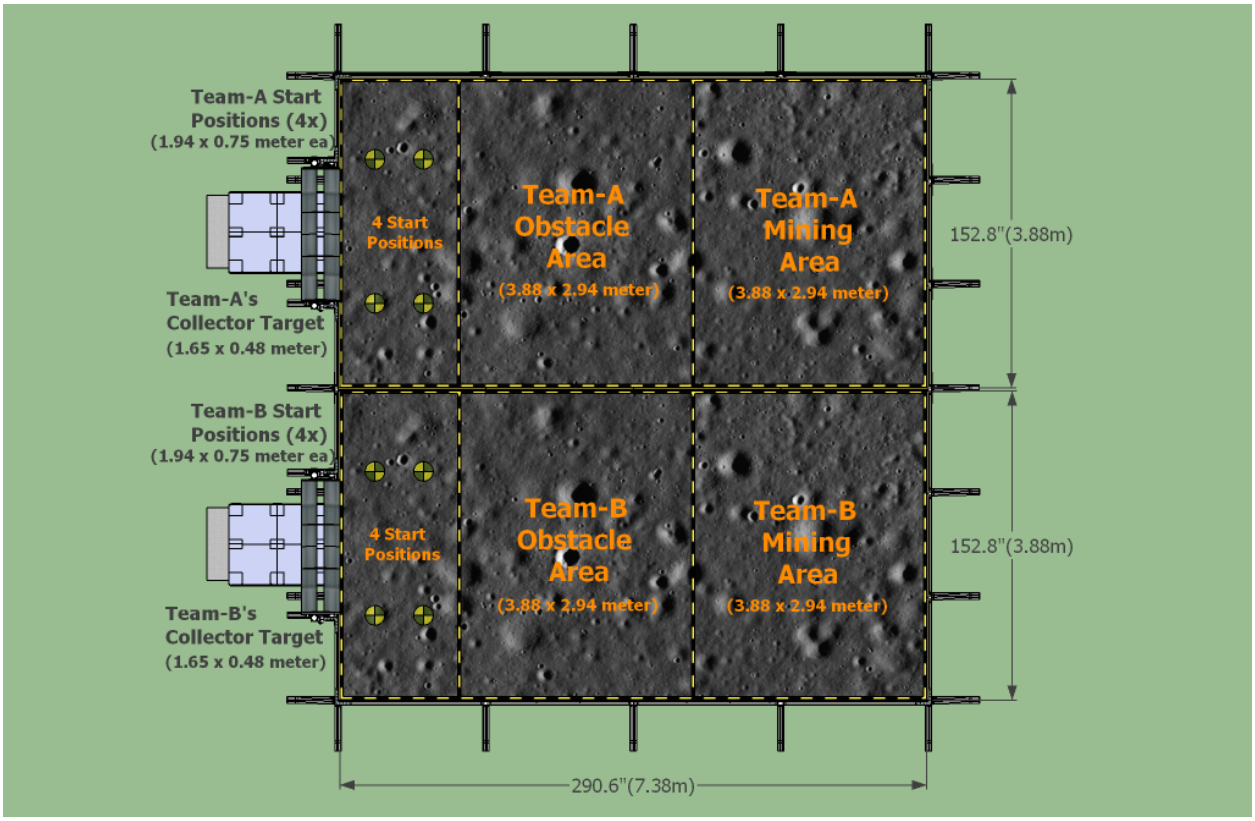

Diagram 2: LunArena (top view)

LunaBin Diagram

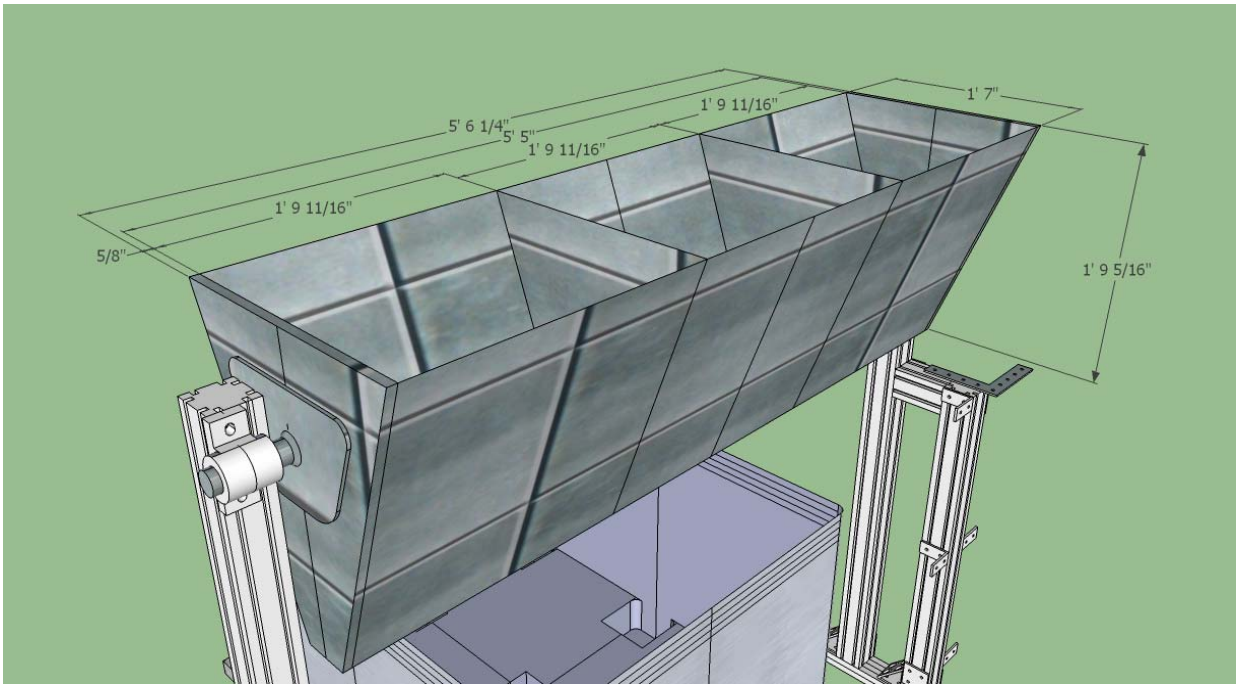

Diagram 3: LunaBin

Lunabotics Systems Engineering Paper

Each team must submit a Systems Engineering Paper electronically in PDF by April 22, 2013, at 12:00 p.m. (noon), eastern time in the United States. Your paper should discuss the systems engineering methods used to design and build your Lunabot. All pertinent information required in the rubric must be in the body of the paper. 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 Systems Engineering Paper. The judges' decision is final. The team with the winning Systems Engineering Paper will receive a team plaque, individual certificates, and a $500 team scholarship. Second-place and third-place winners will receive certificates.

For reference, the NASA Systems Engineering Handbook is available at http://education.ksc.nasa.gov/esmdspacegrant/LunarRegolithExcavatorCourse/Site%20Documents/NASA%20SP-2007-6105.pdf. Additional references, including undergraduate course materials in Systems Engineering, are available at www.spacese.spacegrant.org and in the Lunar Regolith Excavator Senior Design Course at http://www.nasa.gov/offices/education/centers/kennedy/technology/LunarRegolithExcavatorSeniorDesignCourse.html.

Lunabotics Systems Engineering Paper Scoring Rubric	
Elements	**Points**
Content: • Formatted professionally, clearly organized, correct grammar and spelling, size 12 font; single-spaced, maximum of 20 pages, not including the cover, table of contents, and source pages. Appendices are allowed and limited to 5 pages. Cover page must include team name, title of paper, full names of all team members, university name, faculty advisor's full name, and the signature of the sponsoring faculty advisor and a statement that he/she has read and reviewed the paper prior to submission to NASA. International teams are highly encouraged to have the paper edited, specifically to reduce grammatical errors. • Purpose Statement must be included and related to the application of systems engineering to the Lunabotics design challenge.	There are 2 points for 2 elements.
Intrinsic Merit: • Cost budget (estimated costs vs. actual costs) • Design philosophy in the context of systems engineering; discuss what your team is optimizing in your design approach (light weight? automation? regolith capacity? etc.) • Schedule of work from inception to arrival at competition • Major reviews: system requirements, preliminary design, and critical design	There are 4 points for 4 elements. Up to 2 additional points may be awarded for exceptional work related to systems engineering intrinsic merit, for a total of 6 points.
Technical Merit: • Concept of operations • System hierarchy • Interfaces • Requirements • Technical budgets (mass, power, and data allocated to components vs. actual mass, power, and data usage) • Trade-off assessments • Reliability • Verification that system meets requirements	There are 8 points for 8 elements. Up to 4 additional points may be awarded for exceptional work related to systems engineering technical merit, for a total of 12 points.

Lunabotics Outreach Project Report

Each team must participate in an educational outreach project in their local community. Outreach examples include actively participating in school career days, science fairs, technology fairs, or extracurricular science or robotic clubs, or setting up exhibits in local science museums or a local library. Other ideas include organizing a program with a Boys and Girls Club, Girl Scouts, Boy Scouts, etc. Teams are encouraged to have fun with the outreach project and share knowledge of robotics, engineering, or lunar activities with the local community.

Each team must submit a report of the Lunabotics Outreach Project electronically in PDF by April 22, 2013, at 12:00 p.m. (noon), eastern time in the United States. 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. The team with the winning outreach project will receive a team plaque, individual certificates, and a $500 team scholarship. Second-place and third-place winners will receive certificates.

Lunabotics Outreach Project Scoring Rubric	
Elements	**Points**
Structure, Content and Intrinsic Merit: • 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. International teams are highly encouraged to have the paper edited, specifically to reduce grammatical errors. • Purpose for this outreach project, identify outreach recipient groups. • Illustrations must appropriately demonstrate the outreach project.	There are 3 points for 3 elements. Up to 2 additional points may be awarded for exceptional work related to outreach intrinsic merit, for a total of 5 points.
Educational Outreach Merit: • The report must effectively describe the outreach project. • The report must describe exactly how the Lunabotics team participated. • The report must reflect how the outreach project inspired others to learn about robotics, engineering, or lunar activities. • 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. Examples include an in-depth or long-term outreach project or follow-up with the participants.	There are 10 points for 5 elements. Up to 5 additional points may be awarded for exceptional work related to educational outreach merit, for a total of 15 points.

Lunabotics Slide Presentation and Demonstration

The Lunabotics Slide Presentation is an optional category in the overall competition. The presentation and demonstration must be no more than 20 minutes, with an additional 5 minutes for questions and answers. It will be judged at the competition in front of an audience, including NASA and private-industry judges. Only student team members may give the presentation and demonstration onsite. The presentations must be submitted electronically in PDF by April 22, 2013, at 12:00 p.m. (noon), eastern time in the United States. A minimum score of 19 out of 24 possible points must be achieved to qualify to win in this category. In the case of a tie, the judges will choose the winning presentation. The judges' decision is final. The team with the winning presentation will receive a team plaque, individual team certificates, and a $500 team scholarship. Second-place and third-place winners will receive certificates.

Lunabotics Slide Presentation Scoring Rubric	
Elements	**Points**
Content, formatting, and illustrations: • Content includes a cover slide (with team name, presentation title, names of team members, university name, and faculty advisor's name). Also includes an introduction slide and referenced sources. • Formatting is readable and aesthetically pleasing, with proper grammar and spelling. International teams are highly encouraged to have the presentation edited, specifically to reduce grammatical errors. • Illustrations support the technical content. • Illustrations show progression of the project and final design.	There are 4 points for 4 elements. Up to 2 additional points may be awarded for exceptional slides, for a total of 6 points.
Technical Merit: • Design Process • Design Decisions • Final Design • Lunabot Functionality • Special Features: highlight what makes the Lunabot unique or innovative	There are 5 points for 5 elements. Up to 4 additional points may be awarded for exceptional work related to technical merit, for a total of 9 points.
Presentation: • Handles slides and equipment professionally • Engages audience and infuses personality • Creative and inspirational • Demonstrates Lunabot under hardwire/pendant control • Answers questions	There are 5 points for 5 elements. Up to 4 additional points may be awarded for an exceptional presentation, for a total of 9 points.

Lunabotics Team Spirit

Lunabotics Team Spirit is an optional category in the overall competition. A minimum score of 12 out of 15 possible points must be achieved to qualify to win in this category. In the case of a tie, the judges will choose the winning team. The judges' decision is final. The team winning the Team Spirit Award at the Lunabotics Mining Competition will receive a team plaque, individual certificates, and a $500 team scholarship. Second-place and third-place winners will receive certificates.

Lunabotics Team Spirit Competition Scoring Rubric				
Elements	**3**	**2**	**1**	**0**
Teamwork: • Exhibits teamwork in and out of the LunArena • Exhibits a strong sense of collaboration within the team • Supports other teams with a healthy sense of competition	All three elements are exceptionally demonstrated.	Three elements are clearly demonstrated.	One or two elements are clearly demonstrated.	Zero elements are clearly demonstrated.
Attitude: • Exudes a positive attitude in all interactions, not limited to competition attempt • Demonstrates an infectious energy by engaging others in team activities • Motivates and encourages own team • Motivates and encourages other teams • Keeps pit clean and tidy at all times	All five elements are exceptionally demonstrated.	Four elements are exceptionally demonstrated.	One to three elements are clearly demonstrated.	Zero elements are clearly demonstrated.
Creativity & Originality: • Demonstrates creativity and originality in team activities, name, and logo • Wears distinctive team identifiers • Decorates team's LunaPit to reflect school/team spirit	All three elements are exceptionally demonstrated.	Three elements are clearly demonstrated.	One or two elements are clearly demonstrated.	Zero elements are clearly demonstrated.
Sportsmanship: • Demonstrates fairness • Shows respect for both authority and opponents • Promotes specific cultural or regional (country/state) pride • Demonstrates fellowship with competitors	All four elements are exceptionally demonstrated.	Three elements are clearly demonstrated.	One or two elements are clearly demonstrated.	Zero elements are clearly demonstrated.
Feedback at Competition	Up to three points for compliment cards collected at the Competition.			

Categories for Bonus Points

Collaboration between a majority school and a designated United States Minority-Serving Institution
Collaboration between a majority school and a designated U.S. minority-serving institution (MSI) must be identified by November 30, 2012. MSI student team members must be active participants in the competition. MSI student team members must submit their student participant forms and transcripts and be indicated on the team roster by January 17, 2013, at 12:00 p.m. (noon), eastern time in the United States, to receive the 10 bonus points. A list of U.S. minority-serving institutions can be found at http://www2.ed.gov/about/offices/list/ocr/edlite-minorityinst.html.

Multidisciplinary Engineering Teams
Team members from each different STEM discipline***** will count for 1 bonus point, up to a maximum of 10. Disciplines will be indicated on the student participant form by January 17, 2013, at 12:00 p.m. (noon), eastern time in the United States. No bonus points will be given in this category if a team has only one discipline represented. If a member of the team is in a STEM discipline that is not on this list, the team lead or faculty advisor may e-mail Susan.G.Sawyer@nasa.gov to request approval of that discipline for the competition.

Aeronautical Engineering
Aerospace Engineering
Astrobiology
Astronautical Engineering
Astronomy
Astrophysics
Atmospheric Sciences
Bacteriology
Biochemistry
Biology
Biophysics
Chemical Engineering
Chemistry
Civil Engineering
Computer Engineering
Computer Science
Electrical Engineering
Engineering Education
Engineering Management
Environmental Engineering
Geography
Geological Engineering
Geosciences
Health Engineering
Industrial/Manufacturing Engineering
Information Technology
Instrumentation Engineering
Materials/Metallurgical Engineering
Mathematics
Mechanical Engineering
Microbiology
Mining Engineering
Natural Resource Management
Nuclear Engineering
Oceanography
Optics
Physics
Software Engineering
Systems Engineering

*****Team members may be from other disciplines, but only STEM disciplines are awarded bonus points.

Mined and Deposited BP-1
Teams not winning first, second, or third place in the Mining Category can earn 1 bonus point toward the Joe Kosmo Award for Excellence for each kilogram of BP-1 mined and deposited, up to a maximum of 10 points.

Categories & Awards

In addition to the awards listed below, school plaques and/or individual team certificates will be awarded for exemplary performance in the following categories:

Category	Required/ Optional	Due Dates	Award	Maximum Points toward Joe Kosmo Award for Excellence
Onsite Mining in the LunArena	Required	May 22–24, 2013	First place: $3,000 team scholarship and Kennedy launch invitations Second place: $2,000 team scholarship and Kennedy launch invitations Third place: $1,000 team scholarship and Kennedy launch invitations Teams not placing 1st, 2nd, or 3rd will receive 1 point per kilogram mined and deposited, up to 10 points	30 25 20 Up to 10
Systems Engineering Paper	Required	April 22, 2013	$500 team scholarship	Up to 20
Outreach Project Report	Required	April 22, 2013	$500 team scholarship	Up to 20
Slide Presentation and Demonstration	Optional	April 22, 2013 and Onsite on May 22–24, 2013	$500 team scholarship	Up to 24
Team Spirit Competition	Optional	All Year	$500 team scholarship	Up to 15
Collaboration With a Minority Serving Institution	Optional	Nov. 30, 2012		10 bonus points
Multidisciplinary Team	Optional	Jan. 17, 2013		Up to 10 bonus points
Joe Kosmo Award for Excellence	Grand Prize for Most Points	All Year	A school trophy, $5,000 team scholarship, and KSC launch invitations	Total of above points, maximum of 129 points possible
Judges' Innovation Award	Optional	May 22-24, 2013	A school trophy	
Efficient Use of Communications Power Award	Optional	May 22-24, 2013	A school trophy	
Caterpillar's Full Autonomy Award*	Optional	May 22-24, 2013	First place: $1,500 team scholarship Second place: $750 team scholarship Third place: $250 team scholarship	
Best Use of Social Media	Optional	All Year	A school trophy	

*The criteria for Caterpillar's Full Autonomy Award: 500 points for each competition attempt that successfully achieves full autonomy and a minimum of 10 kg. Scores from both competition attempts will be averaged. In the case of a tie, the team that collected the most regolith wins.

Lunabotics Checklist

All documents are due by 12:00 p.m. (noon), eastern time in the United States.

Required Competition Elements

If required elements are not received by the due dates, then the team is not eligible to compete in any part of the competition (NO EXCEPTIONS).

☐ Registration Application*****	50 teams are registered
☐ Systems Engineering Paper**	April 22, 2013
☐ Outreach Project Report**	April 22, 2013
☐ Onsite Mining	May 22–24, 2013
o Team Check-in, Unload/Uncrate Lunabot	May 20, 2013 by 3:00 p.m.
o Practice Days	May 20–21, 2013
o Competition Days	May 22–24, 2013
o Awards Ceremony	May 24, 2013 (evening)

Optional Competition Elements

☐ Presentation File**	April 22, 2013
☐ Team Spirit	All year

Required Documentation

☐ Registration Application	First Come/First Serve
☐ Letter of Support from lead university's Faculty Advisor	With Complete Application
☐ MSI Collaboration Notification	November 30, 2012
☐ Letter of Support from lead university's Dean of Engineering	January 17, 2013
☐ Team Roster with MSI students indicated	January 17, 2013
☐ Student Participant Form	January 17, 2013
☐ Faculty Participation Form	January 17, 2013
☐ Transcripts (unofficial copy is acceptable)*******	January 17, 2013
☐ Signed Media Release Form	January 17, 2013
☐ Corrections to NASA generated Team Roster	February 25, 2013
☐ Request for Team Invitation Letter for International Teams********	February 25, 2013
☐ Team Photo including faculty (high resolution .jpg format preferred)	March 25, 2013
☐ Team Biography (200 words maximum)	March 25, 2013
☐ Head Count Form	March 25, 2013
☐ Revised Team Roster (no changes accepted after this date)	March 25, 2013
☐ Rule 31 documentation	April 30, 2013
☐ Rule 32 video	April 30, 2013
☐ Shipping Bill of Lading/Commercial Invoice	April 30, 2013

Optional Documentation

☐ Student Resume (optional)	January 17, 2013

***** Registration is limited to the first 50 approved teams. Registration is limited to one team per university campus. Internationally, registration is limited to 5 teams per country. Registration will end when NASA approves 50 applications.

****** International teams are highly encouraged to have their submissions edited, specifically to reduce grammatical errors.

******* Each student's Transcript or Statement of Marks must be from the university and show:

- name of university
- name of student
- major course of study
- current student status within the 2012–2013 academic year
- coursework taken and grades

******** International team's invitation letters for visa request purposes will be mailed during the week of February 25, 2013, with only the names of faculty advisors and student team members on the team roster who have completed their participant forms and submitted their transcripts or statement of marks. NASA will not provide individual letters.

Definitions

Autonomous – The operation of a team's Lunabot with no human interaction.

Black Point-1 (BP-1) – A crushed lava basalt aggregate with a natural particle size distribution similar to that of lunar soil. There are naturally occurring rocks in the BP-1 aggregate. The density of the compacted BP-1 aggregate will be between 1.5 g/cm^3 and 1.8 g/cm^3. Approximately 2 cm at the top will be raked to a fluffy condition of approximately 0.75 g/cm^3. BP-1 behaves very similarly to actual lunar soil; however, it does not behave like sand. The study on BP-1 is available on www.nasa.gov/lunabotics. Also, watch the Lunabotics Webcast where Dr. Philip Metzger, a NASA physicist, describes BP-1 and its behavior. It is available at http://youtu.be/hMfrv7mlxbE. The coefficient of friction and the cohesion of lunar soil have not been precisely measured due to difficulties in working with tiny samples. Instead, they have been estimated via a variety of techniques. Both parameters (coefficient of friction and cohesion) are highly dependent on the compaction (bulk density, porosity) of the lunar soil. The paper at this link discusses these relationships and provides estimates for the mechanical property values for lunar soil: http://mars.mines.edu/pub/72MechPropLunarSoil.pdf. The properties are similar to the lunar regolith as stated in *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. Teams are encouraged to develop or procure simulants based on lunar type of minerals and lunar regolith particle size, shape, and distribution. BP-1 is not commercially available. However, JSC-1A is available from Orbital Technologies at http://www.orbitec.com/store/simulant.html, and NU-LHT is commercially available from Zybek Advanced Products (ZAP) at http://www.zybekap.com/.

Competition attempt – The operation of a team's Lunabot, 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 deposited to the LunaBin by the team's Lunabot during each competition attempt, measured in kilograms (kg), with official result recorded to the nearest tenth of a kilogram (0.1 kg).

Functional task – The excavation of BP-1 from the LunArena by the Lunabot and deposit of BP-1 from the Lunabot into the LunaBin.

Minimum excavation requirement – 10.0 kg is the minimum mass that the team's Lunabot must excavate in order to qualify to win the competition.

Practice time – Teams will be allowed to practice with their Lunabots in the LunArena. NASA technical experts will offer feedback on real-time networking performance during practice attempt. Only one practice attempt is guaranteed.

Reference point – A fixed location signified by an arrow showing the forward direction on the Lunabot that will serve to verify the starting orientation of the Lunabot within the LunArena.

LunaBin – A collector bin in NASA's Lunabotics Mining Competition, provided by NASA for each competition attempt, into which each team will deposit excavated BP-1. The LunaBin will be large enough to accommodate each team's excavated BP-1. The LunaBin will be stationary and located next to the LunArena. See Diagram 3.

Lunabot – A teleoperated or autonomous robotic excavator in NASA's Lunabotics Mining Competition, including mechanical and electrical equipment, batteries, gases, fluids, and consumables, delivered by a team to compete in the competition.

LunaPoints – Points earned from the two competition attempts in NASA's Lunabotics Mining Competition will be averaged to determine ranking in the onsite Mining Category.

Lunarlike – Basis of merit associated with feasibility of

1. low volume: being packaged into a small stowed volume for transportation to the moon (1.5 m × 0.75 m × 0.75 m),
2. low mass: it costs $5,000 per kilogram to send mass to low Earth orbit and about $80,000 per kilogram to the lunar surface,
3. simple and reliable operation: ability to be operated for 5 years without maintenance on the lunar surface,

4. lunar-dust tolerance,
5. ease of teleoperation, and
6. ability to survive a lunar night.

LunArena – An open-topped container (i.e., a box with a bottom and four side walls only), containing BP-1, within which the Lunabot will perform each competition attempt. The inside dimensions of the each side of the LunArena will be 7.38 meters long, 3.88 meters wide, and 1 meter deep. The BP-1 aggregate will be approximately 0.5 meters in depth and approximately 0.5 meter from the top of the walls to the surface. A dividing wall will be in the center of the LunArena. The LunArena for the practice days and official competition will be provided by NASA. The LunArena will be outside in an enclosed tent. The LunArena lighting will consist of fluorescent lights inside a tent structure with clear sides. Assume daylight conditions. The atmosphere will be an air-conditioned tent, without significant air currents, and cooled to approximately 77 degrees Fahrenheit. See Diagrams 1 through 3.

Telerobotic – Communication with and control of the Lunabot 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 per second on all data and video sent to and received from the Lunabot.

Time limit – 10 minutes to set up the Lunabot in the LunArena, 10 minutes for the Lunabot to perform the functional task, and 5 minutes to remove the Lunabot.