

NASA

National Aeronautics and
Space Administration



Robotic Mining Competition

Kennedy Space Center Visitor Complex

May 16 - 20, 2016

Kennedy Space Center
Visitor Complex

**Design it.
Build it.
Dig it.**



Rules and Rubrics

For more information visit:
www.nasa.gov/nasarmc

Artwork by
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www.nasa.gov

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NASA Robotic Mining Competition Rules and Rubrics
May 16-20. 2016
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See the changes:

Page 7, **On-Site Mining**

Page 27-28, **NASA's Robotic Mining Competition Social Media and
Public Engagement**

Introduction

NASA's Robotic Mining Competition is for university-level students to design and build a mining robot that can traverse the simulated Martian chaotic terrain. The 'bot must then excavate the basaltic regolith simulant (called Black Point-1 or BP-1) and the ice simulant (gravel) and return the excavated mass for deposit into the Collector Bin to simulate an off-world mining mission. The complexities of the challenge include 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. The On-Site Mining category will require teams to consider a number of design and operation factors such as dust tolerance and dust projection, communications, vehicle mass, energy / power required, and autonomy.

NASA will directly benefit from the competition by encouraging the development of innovative robotic excavation concepts from universities which may result in clever ideas and solutions which could be applied to an actual excavation device and/or payload retrieval mission. The unique physical properties of basaltic regolith and the reduced 3/8th of Earth gravity make excavation a difficult technical challenge. Advances in Martian mining have the potential to significantly contribute to our nation's space vision and NASA space exploration operations.

The competition consists of the following mandatory categories: (1) On-Site Mining, (2) Systems Engineering Paper & (3) Outreach Project

Teams may also compete in the following optional categories: (4) Slide Presentation / Demonstration & (5) Social Media and Public Engagement

To win The Joe Kosmo Award for Excellence teams must compete in all five categories.

Awards

The CATERPILLAR® Autonomy Award

The teams with the first, second and third most autonomous points averaged from both attempts will receive the Caterpillar Autonomy Award and \$1,500, \$750, and \$250 team scholarships respectively. Points will count toward the Caterpillar Autonomy Award even if no regolith is deposited. In case of a tie, the team that deposits the most regolith will win. If no regolith is deposited in a tie, the judges will choose the winner. The judges' decision is final.

The Judge's Innovation Award

The team with most innovative design as designated by the mining judges will receive the Judge's Innovation Award.

The Efficient Use of Communications Power Award

Awarded for using the lowest average data utilization bandwidth per regolith points earned during timed and NASA monitored portion of the competition. Teams must collect the minimum BP-1 and / or icy regolith simulant (gravel) to qualify for this award.

Robotic Mining Competition Awards

(1) On Site Mining, (2) Systems Engineering Paper, (3) Outreach Project Report, (4) Slide Presentation and Demonstration & (5) Social Media and Public Engagement

Awards

THE JOE KOSMO AWARD FOR EXCELLENCE

The team that can use telerobotic or autonomous operations to excavate the resources and score the most points in the mandatory and optional competition categories will win the Joe Kosmo Award for Excellence.

Eligible Teams

Any U.S. college or university located in the United States, its Commonwealths, Territories and / or possessions. One team per university campus will be allowed to compete. The teams shall consist of undergraduate and graduate students (minimum of two undergraduate students) enrolled during the current or previous school semester. The number of team members is at the discretion of the school but should have a sufficient number of members to successfully design, build and operate their mining robot. The teams must include a current faculty member/advisor with the college or university.

Registration

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Registration for eligible teams will open August 24, 2015, 12:00 p.m. (noon) eastern time and is limited to the first 50 approved teams.

ROBOTIC TEAMS REGISTER HERE

<https://www.spacegrant.org/forms/?form=nasarmc>

Day One Check-In

The Robotic Mining Competition Check-In Tent, located in Parking Lot 4 of the Kennedy Space Center Visitor Complex, will open from 7:00 a.m. to 3:00 p.m. on Monday May 16, 2016. The Faculty Advisor and the Team Lead will provide their cell phone number at registration. The number will be used to contact the teams to pass on information (weather alerts, etc.). The Team Lead will be the liaison between their team and the Pit Crew Chief.

Code of Conduct

The NASA Robotic Mining Competition is held in a professional and positive environment. Competitors shall be courteous, professional and conduct themselves with the integrity required by this event. Behavior inconsistent with this philosophy will not be tolerated and shall be grounds for disqualification.

Respiratory Advisory

The Black Point-1 (BP-1) Lunar / Martian Basaltic Regolith Simulant used in the competition contains a small percentage of respirable silica which is a respiratory hazard regulated by Occupational Safety & Health Administration (OSHA). All participants must use a properly functioning mask and respirator. Without exception, proper use of such masks and/or respirators will require a clean shaven face as determined by the Arena Chief.

Frequently Asked Questions (FAQ)

The frequently asked questions (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 Robotic 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 as required by NASA.

In-Situ Resource Utilization

The Competition is a university-level competition designed to find alternative practices of harnessing resources on off-world exploration sites called in-situ resource utilization (ISRU). As we embark on deep-space missions with weeks or months long travel times, ISRU becomes increasingly important because resupply missions are expensive and exclusively relying on them may put crews at risk. Long-duration habitation, surface systems and human life support systems will evolve through NASA's capability-driven approach to exploration, but even the most sophisticated designs must include ISRU components when possible. These research and technology development areas will focus on technologies necessary to extract consumables (O₂, H₂O, N₂, He, etc.) for human life-support system replenishment, source materials for In-Situ fabrication and repair technologies, and source materials (composites, etc.) such as radiation shielding for shelters. Mission capabilities and return on investment multiply when human consumables and spacecraft propellant can be harvested from extraterrestrial environments.

One critical resource on Mars is water ice which can be found buried in the regolith where it is well insulated. The technology concepts developed by the university teams for this competition conceivably could be used to robotically mine regolith resources on Mars and other off-world mission sites. NASA expects the Competition to have 50 teams registered to compete.

The terms "mining robot", "robot", "robots", "mining bot", "bot" & "bots" shall be used interchangeably throughout this document since teams may choose to use one robot or a system of multiple robots that comply with the regulations contained herein. For more information, visit the NASA Robotic Mining Competition on the Web at <http://www.nasa.gov/nasarm> and follow the NASA Robotic Mining Competition on Facebook and Twitter.

Accreditation Board for Engineering and Technology (ABET)

NASA's Robotic Mining Competition rules and rubrics are designed with two goals in mind.


The first goal is to provide the competition environment for university-level students to design and build a mining robot that can traverse the simulated Martian chaotic terrain. Then excavate the basaltic regolith simulant (called Black Point-1 or BP-1) and the ice simulant (gravel) and return the excavated mass for deposit into the Collector Bin to simulate an off-world mining mission. The competition also requires the teams to submit a Systems Engineering Paper, Outreach Project Report and a Slide Presentation &

Demonstration for NASA Peer Review. The competition requirements have practical on and off-world applications for the students and their teams now and in their future.

The second, to align the competition requirements with the general criteria and criterion for student outcomes of the Accreditation Board for Engineering and Technology (ABET). ABET accreditation sets the global standard for programs in applied science, computing, engineering, and engineering technology (<http://www.abet.org>). By competing in NASA's RMC students will be better prepared to attain those program educational objectives set by ABET. The student educational objectives are listed as outcomes (a) through (k), plus any additional outcomes that may be articulated by the ABET program.

- (a) an ability to apply knowledge of mathematics, science, and engineering
- (b) an ability to design and conduct experiments, as well as to analyze and interpret data
- (c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
- (d) an ability to function on multidisciplinary teams
- (e) an ability to identify, formulate, and solve engineering problems
- (f) an understanding of professional and ethical responsibility
- (g) an ability to communicate effectively
- (h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
- (i) a recognition of the need for, and an ability to engage in life-long learning
- (j) a knowledge of contemporary issues
- (k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

For updates, please go to the Accreditation Board for Engineering and Technology (ABET), Criteria for Accrediting Engineering Programs website (<http://www.abet.org>).

Check out the Robotic Mining Competition on 

Engineer It!

https://www.youtube.com/watch?v=L53u_-22sXU

Ver ¡Buscamos estudiantes a los que les entusiasmen los robots!

(Wanted: Student Robot Enthusiasts)

<https://www.youtube.com/watch?v=SjX3Q5GUmrrs>

NASA's Robotic Mining Competition Wraps Up at Kennedy Space Center

<https://www.youtube.com/watch?v=5gLfrTCk8XU&feature=youtu.be>

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RULES & RUBRICS

On-Site Mining

A minimum amount of 10 kg of BP-1 must be mined and deposited during either of two competition attempts according to the rules to qualify to win in this category. If the minimum amount of 10 kg of BP-1 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 judges' decisions are final in all disputes.

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 kilogram of BP-1 and/or icy regolith simulant (gravel) mined and deposited up to a maximum average of ten points.

Mining Category Elements	Specific Points	Actual	Units	Mining Points
Pass Inspections	0 or 1000	1		1000
BP-1 over 10 kg	+3 /kg	110	kg	+300
Gravel (Icy Regolith Simulant)	+15 /kg	10	kg	+150
Average Data Utilization Bandwidth	-1/50 kb/s	5000	kb/s	-100
Mining Robot Mass	-8/kg	80	kg	-640
Report Energy Consumed	-1/Watt-hour	-35	Watt-hour	-35
Dust Tolerant Design (30%) & Dust Free Operation (70%)	0 to +100	70	X	+70
Autonomy	50, 150, 250 or 500	150	X	+150
Total	X	X	X	895

Table 1: Mining Category Scoring Sheet

1) Competition

Teams will be required to perform two official competition attempts using BP-1 in the Caterpillar Mining Arena. The Arenas are filled with compacted BP-1 that approximates basaltic Martian regolith. The mining area will contain BP-1 up to a depth of approximately 30 cm. Below the BP-1 there will be approximately 30 cm depth of gravel with a mean particle size diameter of ~ 2 cm which simulates icy regolith buried in the Martian regolith. Larger rocks may also be mixed in with the gravel and BP-1 in a random manner. Note that gravel may be mixed in with the BP-1, but the bulk of it will be in the bottom 30 cm of the mining area only. Three obstacles will be randomly placed and create two craters on each side of the Arenas. 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 gravel will be returned to the lower 30 cm of the mining area

and the BP-1 will be returned to the top 30 cm in a compacted state, and the obstacles and craters will be re-set in the Arena. The competition attempts will be chosen at NASA's discretion.
See Diagrams 1 & 2.

2) In each of the two official competition attempts, the teams will score cumulative Mining Points. See Table 1 for the Mining Category Scoring Sheet. The teams' Mining Points will be the average of their two competition attempts.

- a) Each team will be awarded 1000 Mining points after passing the safety inspection and communications check.
- b) During each competition attempt, the team will earn 3 Mining points for each kilogram in excess of 10 kg of BP-1 deposited in the Collector Bin. (For example, 110 kg of BP-1 mined will earn 300 Mining points.)
- c) During each competition attempt, the team will earn 15 Mining points for each kilogram of simulated icy regolith (gravel) deposited in the Collector Bin. The gravel will be sieved out at the Collector Bin and weighed separately from the BP-1.
- d) During each competition attempt, the team will lose 1 Mining point for each 50 kilobits/second (kb/s) of average data used.
- e) During each competition attempt, the team will lose 200 kb/s of data for each situation situational awareness camera used.
- f) 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 80 kg will lose 640 Mining points).
- g) During each competition attempt, the team will lose 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.
- h) During each competition attempt, the judges will award the team 0 to 100 Mining points for dust tolerant design features on the mining robot (up to 30 Mining points) and dust free operation (up to 70 Mining points). If the mining robot has exposed mechanisms where dust could accumulate during a Martian mission and degrade the performance or lifetime of the mechanisms, then fewer Mining points will be awarded in this category. If the mining robot raises a substantial amount of airborne dust or projects it due to its operations, then, fewer Mining points will be awarded. 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:
 - i. Drive train components enclosed/protected and other component selections 10 points
 - ii. Custom dust sealing features (bellows, seals, etc.) 10 points
 - iii. 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:
- | | | |
|------|--|-----------|
| i. | Driving without dusting up crushed basalt | 20 points |
| ii. | Digging without dusting up crushed basalt | 30 points |
| iii. | Transferring crushed basalt without dumping the crushed basalt on your own Robot | 30 points |
- k) **AUTONOMOUS OPERATION** - During each competition attempt, the team will earn up to 500 Mining points for autonomous operation. Mining points will be awarded for successfully completing the following activities autonomously:
- | | | |
|------|--|------------|
| i. | Crossing the obstacle field (two times only, Outbound and back): | 50 points |
| ii. | Crossing the obstacle field, excavate and returning to the collection bin: | 150 points |
| iii. | Crossing the obstacle field, excavate and depositing regolith (two times): | 250 points |
| iv. | Fully autonomous run for 10 minutes: | 500 points |
- l) The points earned for autonomy are not cumulative. Levels 1 through 4 points will be incrementally achieved. For example if level 2 is achieved then the points for level 1 are not counted. The autonomy points are awarded for the whole competition attempt and not for each run across the obstacle zone. If the robot fails to achieve autonomy during the competition attempt, and manual control is regained, then only autonomy points achieved to that point in time will be allowed.
- m) For a team to earn mining points in the autonomous category, the team cannot touch the controls during the autonomous period. If the team touches the controls, then the autonomy period for that run is over; however, the team may revert to manual control to complete that run. Start and stop commands are allowed at the beginning and end of the autonomous period. 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. The mining robot must continue to operate for the entire 10 minutes to qualify for a fully autonomous run.
- n) The walls of the Caterpillar 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 Mars and teams shall operate as closely as possible to a Mars 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) All excavated mass deposited in the Collector Bin during each official competition attempt will be weighed after the completion of each competition attempt. All gravel will be sieved out from the BP-1 at the Collector Bin and weighed separately.
- 5) The mining robot will be placed in the randomly selected starting positions. See Diagrams 1 and 2.
- 6) A team's mining robot may only excavate BP-1 and gravel located in that team's respective mining area at the opposite end of the Caterpillar Mining Arena 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 by the front end of the robot.
- 7) The mining robot is required to move across the obstacle area to the mining area and then move back to the Collector Bin to deposit the BP-1 and gravel into the Collector Bin. See Diagrams 1 and 2.
- 8) Each team is responsible for placement and removal of their mining robot onto the BP-1 surface. There must be one person per 23 kg of mass of the mining robot, requiring four people to carry the maximum allowed mass. Assistance will be provided if needed.

- 9) Each team is allotted a maximum of 5 minutes to place the mining robot in its designated starting position within the Caterpillar Mining Arena; and remove the mining robot from the Caterpillar Mining Arena after the 10-minute competition attempt has concluded and as directed by the Mining Judge.
- 10) The mining robot operates during the 10-minute time limit of each competition attempt. The competition attempts for both teams in the Caterpillar Mining Arena will begin and end at the same time.
- 11) The mining robot will end operation immediately when the power-off command is sent, as instructed by the Mining Judge.
- 12) The mining robot cannot be anchored to the BP-1 surface prior to the beginning of each competition attempt.
- 13) 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.
- 14) At the start of each competition attempt, the mining robot may not occupy any location outside the defined starting position in the Caterpillar Mining Arena. See Caterpillar Mining Arena definition for description of the competition field.
- 15) The collector trough/sieve top front edge will be placed so that it is in the vertical plane of the adjacent end wall of the Caterpillar Mining Arena. The top edge of the sieve will be approximately 0.55 meter \pm 0.05 m from the top of the BP-1 surface directly below it. The sieve screen frame will have the same opening dimensions and internal slope angles as the trough but will be suspended above it. See Diagram 3.
- a) The top opening inner dimensions for both the trough and the sieve screen placed above it are the same: 1.575 m long by 0.457 m deep with the same slope angles of 44 degrees long sides and 51 degrees at the ends.
 - b) With the addition of the sieve screen, the effective height of the collector trough lip is raised by 3.8 cm above the trough alone. The sieve screen is 6.4 cm below the sieve frame top. See Diagrams 1 – 3.
 - c) Target(s) or beacon(s) may be attached to the collector trough (not the sieve frame) for navigation purposes only. This navigational aid system must be attached during the setup time and removed afterwards during the removal time period. If attached to the collector trough, it must not exceed the length of the Collector trough and it must not weigh over 9 kg.
 - d) The outside dimensions of the collector trough and sieve frame are 1.65 meters long and .48 meters wide.
 - e) The navigational aid system may not be higher than 0.25 m above the Collector Trough, and cannot be permanently attached or cause alterations (ex: no drilling, nails, etc.).
 - f) The mass of the navigational aid system is included in the maximum mining robot mass limit of 80.0 kg and must be self-powered.
 - g) The target/beacon may send a signal or light beam but lasers are not allowed for safety reasons except for Visible Class I or II lasers or low power lasers and laser based detection systems.
 - h) Supporting documentation from the laser instrumentation vendor must be given to the inspection judge for “eye-safe” lasers.

- i) The judges will inspect and verify that all laser devices are a class I or II product and they have not been modified (optics or power).

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 10 to 30 cm and an approximate mass of 3 to 10 kg. There will be two craters of varying depth and width, being no wider or deeper than 30 cm. No obstacles will be intentionally buried in the BP-1 by NASA, however, BP-1 includes naturally occurring rocks.

17) The mining robot must operate within the Caterpillar Mining Arena: it is not permitted to pass beyond the confines of the outside wall of the Arena and the Collector Bin during each competition attempt. The BP-1 and/or gravel must be mined in the mining area and deposited in the Collector Bin. A team that excavates any BP-1 from the starting or obstacle areas will be disqualified. The BP-1 and/or gravel must be carried from the mining area to the Collector Bin by any means and be deposited in the Collector Bin in its raw state.

A secondary container like a bag or box may not be deposited inside the Collector Bin. Depositing a container in the Collector Bin will result in disqualification of the team. The mining robot can separate intentionally, if desired, but all parts of the mining robot must be under the team's control at all times. 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 at PISCES or on Mars). Touching or having a switch sensor springwire that may brush on a wall as a collision avoidance sensor is not allowed.

18) The mining robot must not use the wall as support or push/scoop BP-1 and/or gravel up against the wall to accumulate BP-1. If the mining robot exposes the Caterpillar Mining Arena bottom due to excavation, touching the bottom is permitted, but contact with the Caterpillar 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.

19) During each competition attempt, the mining robot is limited to autonomous and telerobotic operations only. No physical access to the mining robot will be allowed during each competition attempt. In addition, telerobotic operators are only allowed to use data and video originating from the mining robot and the NASA video monitors. 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 Caterpillar Mining Arena through overhead cameras in the Caterpillar 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. 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 Caterpillar Mining Arena to facilitate voice communications during the setup phase only.

20) The mining robot mass is limited to a maximum of 80.0 kg. Subsystems on the mining robot used to transmit commands/data and video to the telerobotic operators are counted toward the 80.0 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 80.0 kg mass limit.

21) The mining robot must provide its own onboard power. No facility power will be provided to the mining robot. There are no power limitations except that the mining robot must be self-powered and included in the maximum mining robot mass limit of 80.0 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.

22) The mining robot must be equipped with an easily accessible **red** emergency stop button (kill switch). The emergency stop button shall have a minimum diameter of 40 mm on the surface of the mining robot requiring no steps to access. The emergency stop button must stop the mining robot's motion and disable all power to the mining robot 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 is 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 laptop computers may stay powered on if powered by its internal battery.

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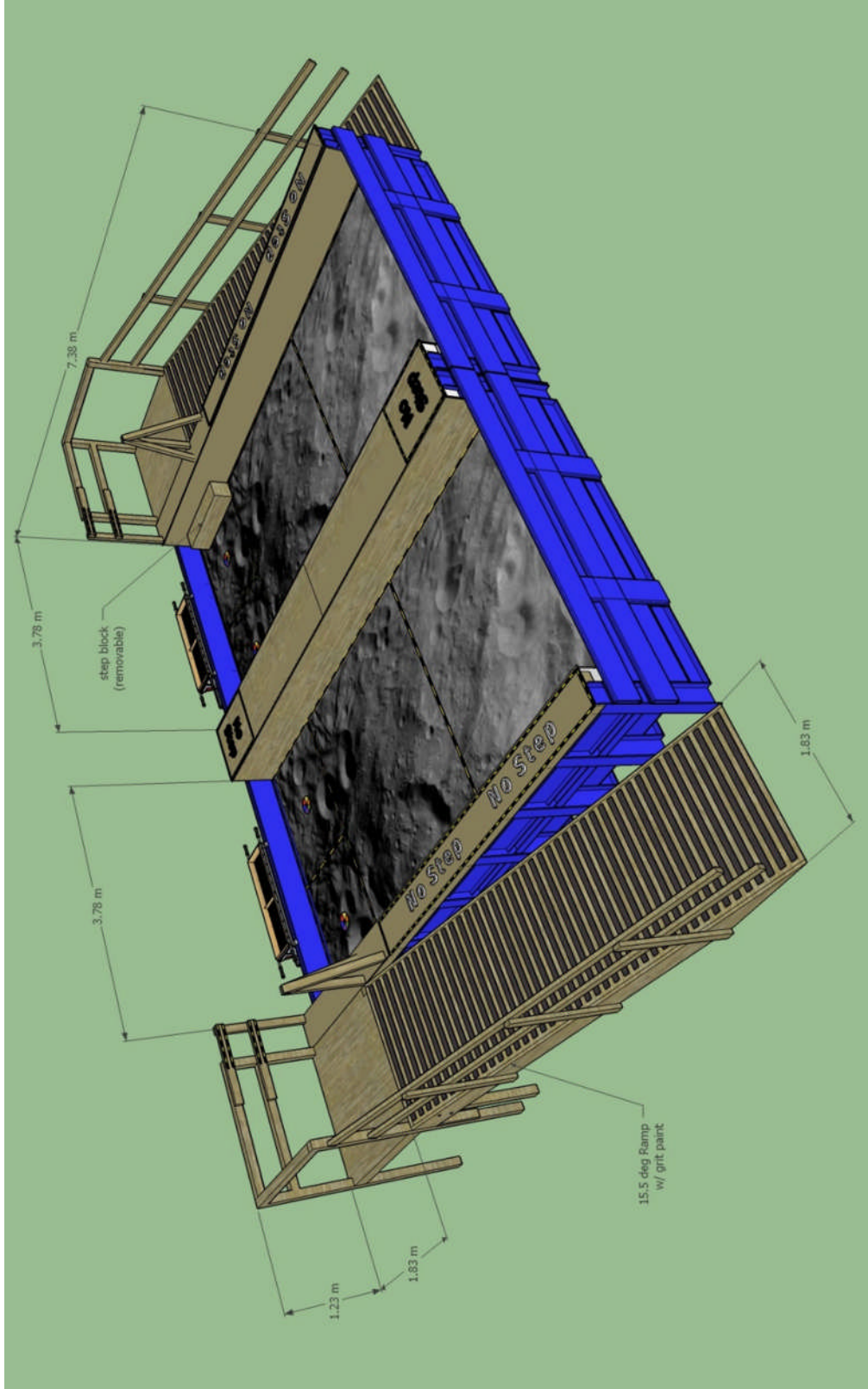


Diagram 1
CATERPILLAR MINING ARENA
Isometric View

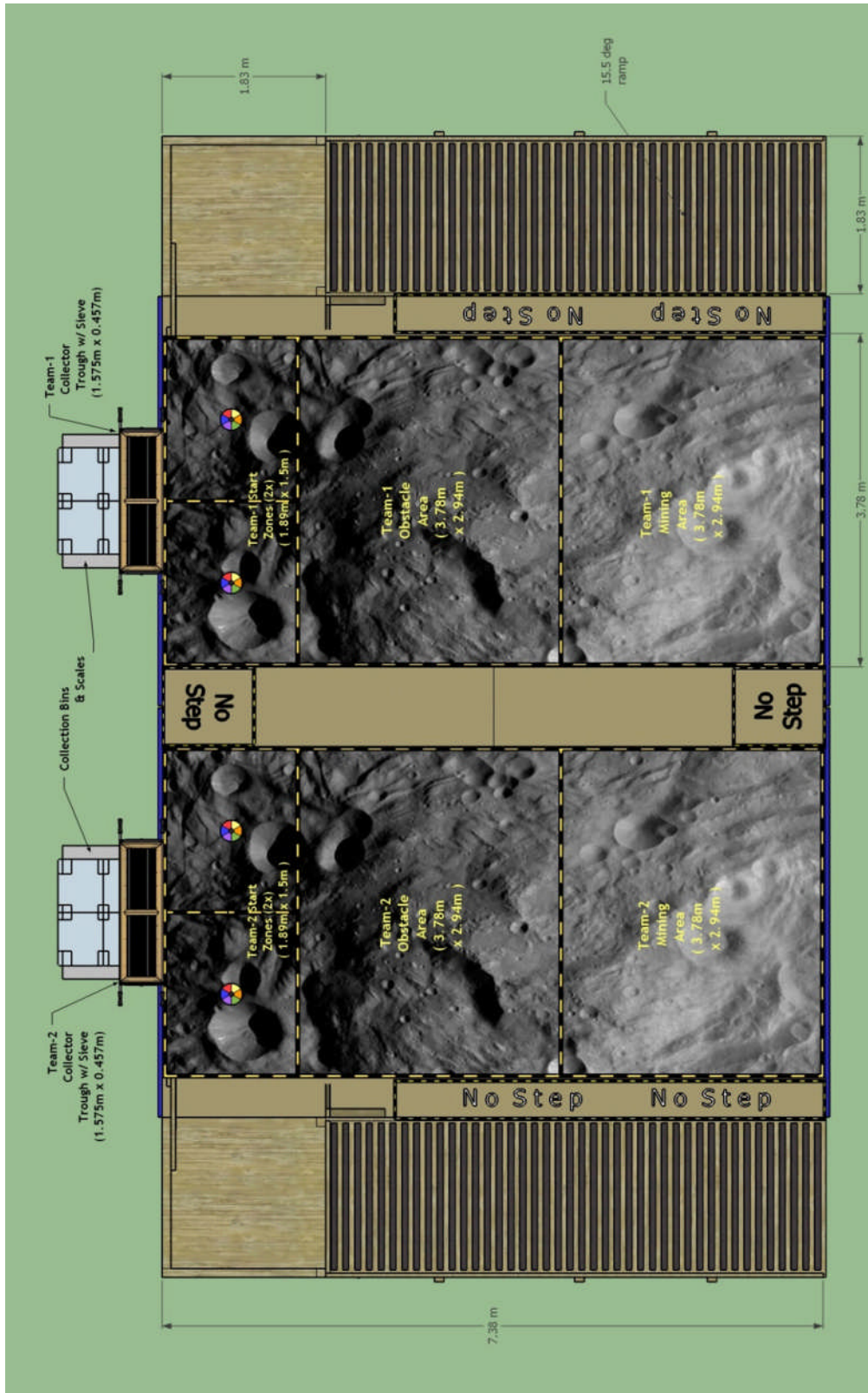


Diagram 2
CATERPILLAR MINING ARENA
Top – Down View

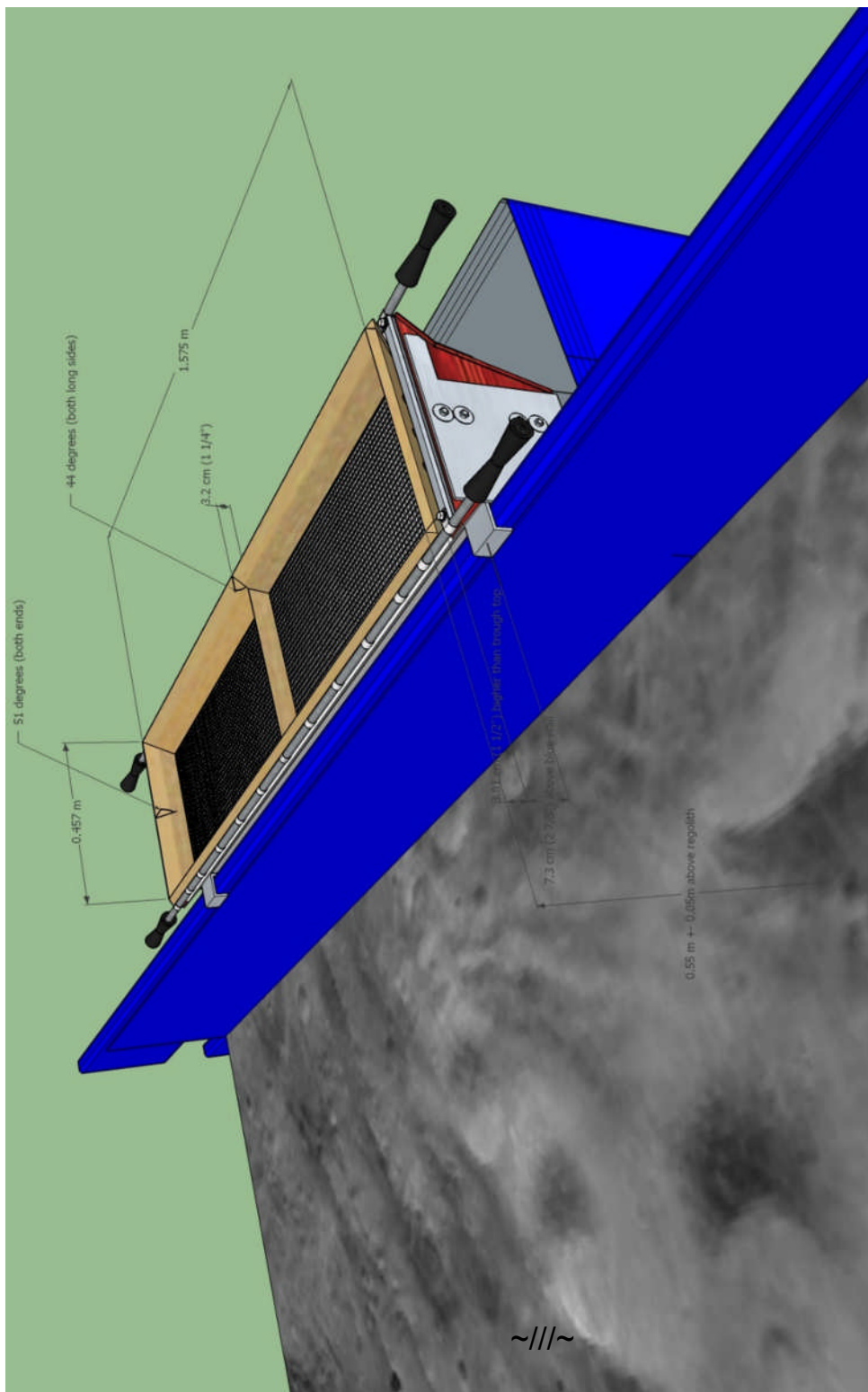


Diagram 3 Excavated Mass Collector Bin Isometric View

RULES & RUBRICS

Communications / Telerobotic Operations

23) Communications / Tele-Robotic Operations

a) Mining Robot Wireless Systems Requirements

- i. Each team is required to command and monitor their mining robot over the NASA provided network infrastructure shown in Figure 1.
- ii. This configuration must be used for teams to communicate with their robot.
- iii. The “Mars Lander” camera is staged in the Caterpillar Mining Arena, and Mars Lander Control Joystick and camera display will be located with the team in the Mission Control Center (MCC).
- iv. The MCC will have an official timing display, which includes a real-time display of BP-1 collected during the match.
- v. Handheld radios will be provided to each team to link their Mission Control Center team members with their corresponding team members in the Caterpillar Mining Arena during setup.

b) 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 Caterpillar Mining Arena.

- i. In the Caterpillar 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.
- ii. The network drop in the Caterpillar Mining Arena will be elevated high enough above the edge of the regolith bed wall to provide adequate radio frequency visibility of the Caterpillar Mining Arena.
- iii. A shelf will be set up next to the network drop at a height 0 to 2 feet 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.
- iv. 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.
- v. The WAP shelves for side A and side B of the Caterpillar Mining Arena will be at least 25 feet apart to prevent electromagnetic interference (EMI) between the units.

c) 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. This will be no more than 5 feet from the shelf.
 - ii. NASA will provide standard US NEMA 5-15 type, 110 VAC, 60 Hz electrical connections in the Mission Control Center for each team.
 - iii. 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.
- d) During the setup phase, the teams will set up their access point and verify communication with their mining robot from the Mission Control Center.

- e) The teams must use the USA IEEE 802.11b, 802.11g, or 802.11n standards for their wireless connection (WAP and rover client).
 - i. 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.
 - ii. Encryption is not required, but it is highly encouraged to prevent unexpected problems with team links.
 - iii. 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.
- f) Teams must be able to use and switch between channel 1 and channel 11 for the competition.
- g) Each team will be assigned an SSID that they must use for the wireless equipment for channel 1 and channel 11.
 - i. SSID will be “Team_##.”
 - ii. Teams are required to broadcast their SSID.
- h) The use of specific low power 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.
- i) The use of 2.4 GHz ZigBee technology is prohibited because of the possibility of interference with the competition wireless transmissions.
- j) 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.
- k) Radio Frequency Power:
 - i. All Team provided wireless equipment shall operate legally within the power requirements power levels 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.
 - ii. 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 is NOT allowed in the competition.
 - iii. This radio frequency power requirement applies to all wireless transmission devices at any ISM frequency.
- l) Data Utilization Bandwidth Constraints
 - i. 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.
 - ii. 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.

m) Radio Frequencies and Communications Approval

- i. 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.
- ii. 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.
- iii. 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.
- iv. 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.
- v. If a team cannot demonstrate the above tasks in the allotted time, the team will be disqualified from the competition.
- vi. 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.
- vii. 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.
- viii. Once the team arrives at the communication judges' station, the team can no longer receive assistance from the NASA communications technical experts.
- ix. If a team is on the wrong channel during their competition attempts, the team will be disqualified and required to power down.

n) Wireless Device Operation in the RoboPits

- i. Teams will not be allowed to power up their transmitters on any frequency in the Pits during the practice matches or competition attempts. All teams must have a hardwired connection for testing in the RoboPits.
- ii. Teams will have designated times to power up their transmitters when no matches are underway.

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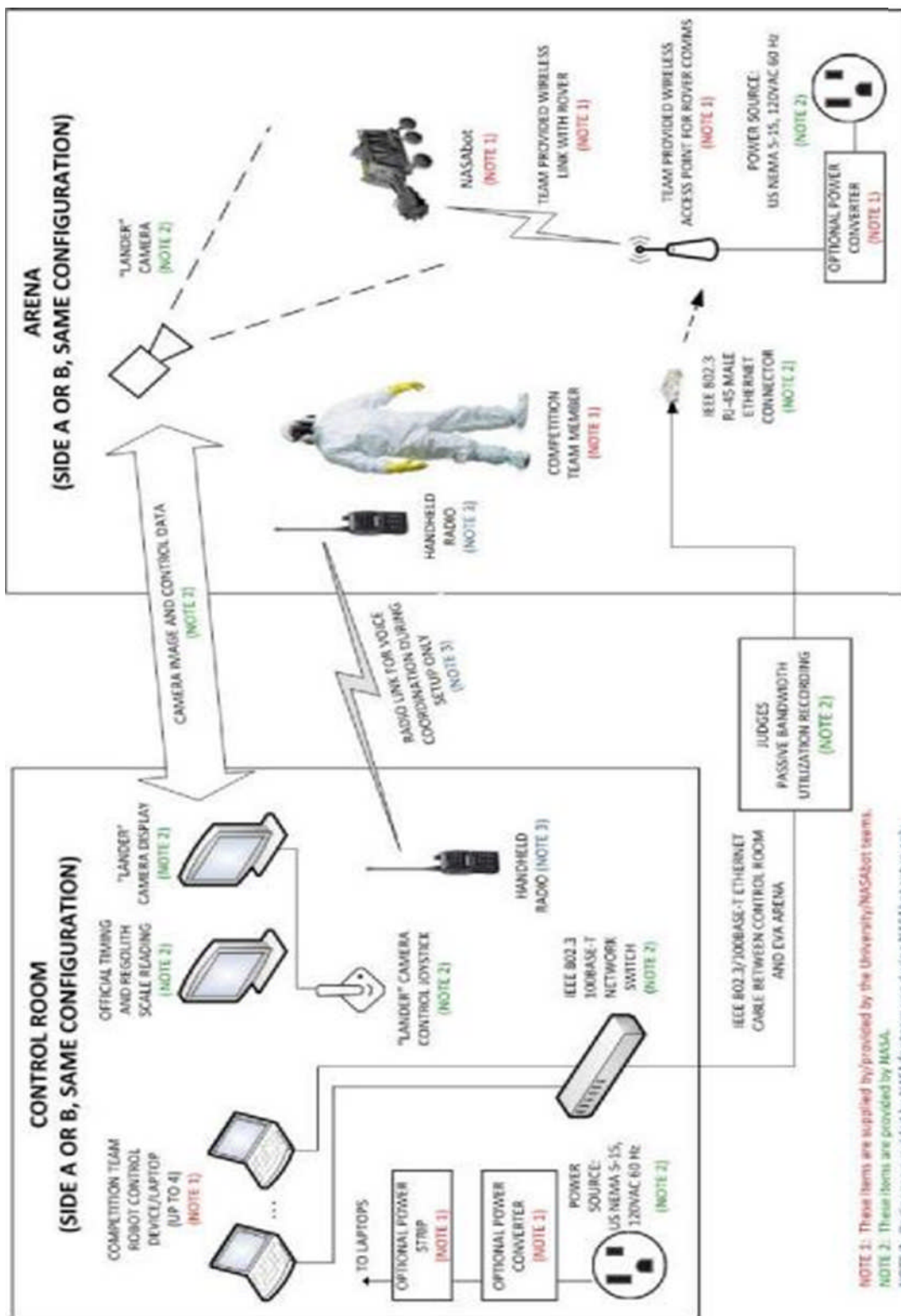
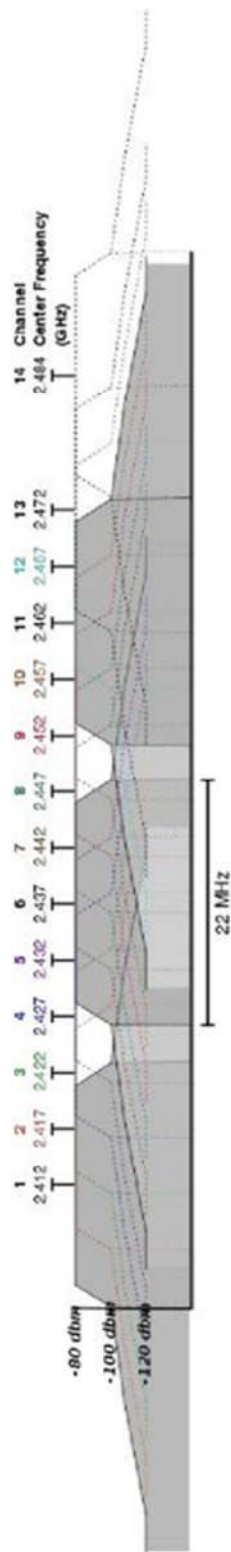
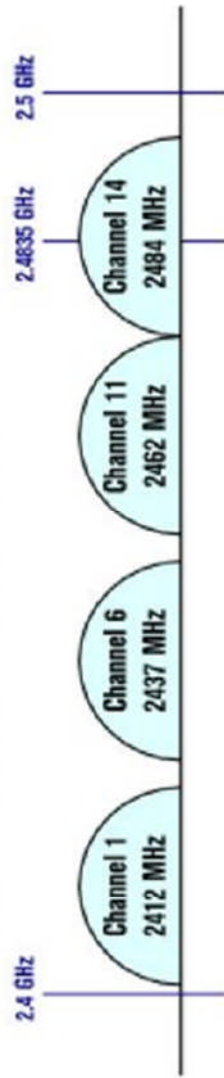


Figure 1
NASA Provided Network



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

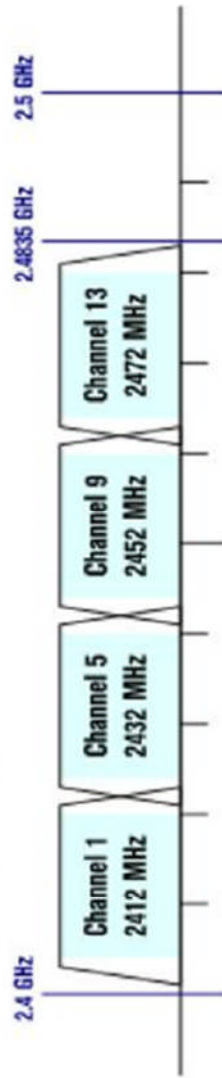


Figure 2
802.11 n Channel

RULES & RUBRICS

Mining Robot

24) The mining robot must be contained within 1.5 m length x 0.75 m width x 0.75 m height. The mining robot may deploy or expand beyond the 1.5 m x 0.75 m footprint after the start of each competition attempt, but may not exceed a 1.5 meter height. During regolith simulant dumping operations only, the mining robot may deploy itself and exceed 1.5 m in height, but must be lower than the height of the ceiling of the tent, which is less than 2.5 m above the surface of the regolith. The mining robot may not pass beyond the confines of the outside wall of the Caterpillar Mining Arena and the Collector Bin during each competition attempt to avoid potential interference with the surrounding tent. The team must declare the orientation of length and width to the inspection judge. Because of actual Martian 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 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. 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.

25) To ensure that the mining robot is usable for an actual Martian mission, the mining robot cannot employ any fundamental physical processes, gases, fluids or consumables that would not work in the Martian environment. For example, any dust removal from a lens or sensor must employ a physical process that would be suitable for the Martian 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 Martian 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.

Note on Florida weather: the mining robot will be exposed to the Florida spring weather as it transitions from the RoboPit Tent (inside temperature approximately 21°C / 70°F) to the Inspection Stations and finally to the Competition Arenas (outside temperature averaging 32°C / 90°F & 95% humidity) during inspection and while waiting to enter the Caterpillar Mining Arena.

26) Components (i.e. electronic and mechanical) are not required to be space qualified for Martian atmospheric, electromagnetic, and thermal environments. Since budgets are limited, the competition rules are intended to require mining robots to show Martian plausible system functionality but the components do not have to be traceable to a Martian 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 a Mars or off-world mission.

27) The mining robot may not use any process that causes the physical or chemical properties of the BP-1 and/or gravel to be changed or otherwise endangers the uniformity between competition attempts.

28) 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.

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

30) No team can intentionally harm another team's mining robot. 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 mining robot as determined by the judges will be cause for immediate disqualification. A judge may disable the mining robot by pushing the **red** emergency stop button at any time.

31) Teams must electronically submit documentation containing a description of their mining robot, its operation, potential safety hazards, a diagram, and basic parts list by April 22, 2016 at 12:00 p.m. (noon) eastern time. via e-mail to Bethanne.Hull@nasa.gov

32) Teams must electronically submit a **link** to their YouTube video documenting no less than 30 seconds but no more than 5 minutes of their mining robot in operation for at least one full cycle of operations (one full cycle of includes excavation and depositing material) by April 22, 2016 at 12:00 p.m. (noon) eastern time via e-mail to Bethanne.Hull@nasa.gov . This video documentation is solely for technical evaluation of the mining robot.

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Shipping Your 'Bots

33) SHIPPING TO THE COMPETITION

Teams are responsible for the cost of shipping and tracking their robots. Remember to use a reputable shipping company and start this process in a timely manner and submit via email your Shipping Bill of Lading / Commercial Invoice by April 22, 2016 to Bethanne.Hull@nasa.gov. The Ship To address and instructions are as follows:

NASA John F. Kennedy Space Center
ISC Central Receiving - Bldg. M6-0744
Kennedy Space Center, FL 32899
Mark For: Robotic Mining Competition at the Kennedy Space Center Visitor Complex

- Do not have the shipping company deliver the mining robot directly to the Kennedy Space Center Visitor Complex.
- The shipping company will come to the NASA KSC Pass & ID Office on the south side of State Road 405. Call 321.749.0320, ISC Central Receiving, will send an escort.
- Your shipping containers will be accepted from 7 a.m. through 2:30 p.m. starting Wednesday May 4, 2016 through Thursday May 12, 2016.
- Coordinate with your shipping company to ensure deliveries are made within this time period. The containers will be placed in each team's assigned RoboPit for the competition.

34) SHIPPING BACK HOME

Return shipping arrangements must be made prior to the competition. Remember to use a reputable shipping company, start this process in a timely manner and submit via email your Shipping Bill of Lading / Commercial Invoice by April 22, 2016. Your Pick-Up address and instructions are as follows:

Kennedy Space Center Visitor Complex
Delaware North Companies (DNC)
Robotic Mining Shipping Area - Mail Code: DNPS
State Road 405
Kennedy Space Center, FL 32899

- At the end of the RMC prepare your robot(s) for shipment and leave your container in your RoboPit.
- Drivers will go directly to the Kennedy Space Center Visitor Complex retail warehouse (behind the DNC Administration Building) through Guard Post 4; from there, the DNC warehouse team will take the driver to the appropriate site where the robots are being stored for pick up.
- The on-site P.O.C. is Charlie Lamattina 321.449.4252, Lamatti@delawarenorth.com.
- Shipping Bill of Lading/Commercial Invoice & shipping crates must have the shipping company name clearly labeled on the crate.
- All mining robots must be picked up from the Kennedy Space Center Visitor Complex no later than 3:00 p.m. on Tuesday, May 24, 2016. Robots remaining will be considered abandoned and will be offered to local area high school robotic programs for adoption.

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RULES & RUBRICS

NASA's Robotic Mining Competition Systems Engineering Paper

Each team must submit a Systems Engineering Paper electronically in PDF. Your paper should discuss the Systems Engineering methods used to design and build your mining robot. The purpose of the systems engineering paper is to encourage the teams to use the systems engineering process while designing, building and testing their robot as opposed to writing a paper after the fact. 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. For reference, undergraduate course materials in NASA Systems Engineering, are available at www.spacegrant.org.

NASA's Robotic Mining Competition Systems Engineering Paper Scoring Rubric	
Elements	Points
Content: <ul style="list-style-type: none"> 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, and should be referenced in main body. Cover page must include: team name, title of paper, full names of all team members, university name, and faculty advisor's full name. Title page must 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. Purpose Statement must be included and related to the application of systems engineering to NASA's Robotic Mining Competition. 	<p>There are 3 points for 3 elements.</p>
Intrinsic Merit: <ul style="list-style-type: none"> 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? BP-1 capacity? ice simulant, etc.) Schedule of work from inception to arrival at competition Major reviews: system requirements, preliminary design and critical design 	<p>There are 4 points for 4 elements.</p> <p>Up to 2 additional points may be awarded for exceptional work related to systems engineering intrinsic merit, for a total of 6 points.</p>
Technical Merit: <ul style="list-style-type: none"> Concept of operations System hierarchy Interfaces Requirements Technical budgets (mass, power & data allocated to components vs. actual mass, power, & data usage) Trade-off assessments Reliability Verification of system meeting requirements 	<p>There are 8 points for 8 elements.</p> <p>Up to 3 additional points may be awarded for exceptional work related to systems engineering technical merit, for a total of 11 points.</p>

NASA's Robotic Mining Competition Outreach Project Report

Each team must participate in an educational outreach project in their local community to engage students in STEM (Science, Technology, Engineering and Math). Outreach activities should capitalize on the excitement of NASA's discoveries to spark student interest and involvement in STEM. 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 Outreach Project electronically in PDF. 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.

NASA's Robotic Mining Competition Outreach Project Report Scoring Rubric	
Elements	Points
Structure, Content and Intrinsic Merit: <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. 	There are 3 points for 3 elements.
Educational Outreach Merit: <ul style="list-style-type: none"> The report must effectively describe what the outreach activity(s) was. The report must describe exactly how the Robotic Mining Competition team participated, including the number of team members present. The report must reflect how the team thinks the outreach project inspired others to learn about robotics, engineering or Martian activities. 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? EACH EVENT NEEDS STATISTICS 	There are 10 points for 5 elements.
Additional points for exceptional work: <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 provide a summary of any feedback comments from each outreach event. The report must clearly describe how Science, Technology, Engineering, and Mathematics (STEM) relates to the development of robotic mining. The report must provide two illustrations that clearly demonstrate how Science, Technology, Engineering, and Mathematics (STEM) relates to the development of robotic mining. 	There are 7 points available.

NASA's Robotic Mining Competition Slide Presentation and Demonstration

The Robotic Mining Slide Presentation and Demonstration 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. The presentations must be submitted electronically in PDF and **MUST** present the slides turned in. Visual aids, such as videos and handouts, may be used during the presentation but videos must be presented using the team's own laptop. You may NOT update/modify your slide presentation and present it from your laptop. A minimum score of 16 out of 20 possible points must be achieved to qualify to win in this category. The content, formatting and illustration portion of the score will be judged prior to the live presentation and scored based on the presentation turned in. In case of a tie, the judges will choose the winning presentation. The judges' decision is final.

NASA's Robotic Mining Competition Slide Presentation and Demonstration Scoring Rubric	
Elements	Points
Content, formatting, and illustrations: <ul style="list-style-type: none"> 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. Illustrations support the technical content Illustrations show progression of the project and final design 	There are 4 points for 4 elements.
Technical Merit: <ul style="list-style-type: none"> Design Philosophy and Process Design Alternative Analysis and Final Design Mining functionality Special features – highlight what makes the robot unique or innovative Project Management 	There are 5 points for 5 elements. Up to 2 additional points may be awarded for exceptional work related to technical merit, for a total of 7 points.
Presentation: <ul style="list-style-type: none"> Handles slides and equipment professionally Engages audience and infuses personality Creative and inspirational Demonstrates Robot 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.

NASA's Robotic Mining Competition Social Media and Public Engagement

NASA's Robotic Mining Competition Social Media and Public Engagement 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.

NASA's Robotic Mining Competition Team Spirit Competition Scoring Rubric				
Elements	3	2	1	0
Social Presence: <ul style="list-style-type: none"> Uses various social media platforms to engage the public in their participation in RMC Engages with NASA and other robotic teams Encourages other groups to engage in social media activities with their team 	All three elements are exceptionally demonstrated	Three elements are clearly demonstrated	Two or less elements are clearly demonstrated	Zero elements are clearly demonstrated
Content: <ul style="list-style-type: none"> Creatively engages the public in robotics and STEM related topics Showcases their universities progress in the design and build of their robot Motivates and encourages K-12 robotic groups to showcase their robots Educates the public about robotics and the current NASA missions 	All four elements are exceptionally demonstrated	three elements are exceptionally demonstrated	Two or less elements are clearly demonstrated	Zero elements are clearly demonstrated
On-Site Public Engagement: <ul style="list-style-type: none"> Exudes a positive attitude in all interactions Conducts themselves as positive role models Demonstrates courtesy with authority & competitors 	All five elements are exceptionally demonstrated	Four elements are clearly demonstrated	Three or less elements are clearly demonstrated	Zero elements are clearly demonstrated

<ul style="list-style-type: none"> Decorates team's Pit to reflect school/team spirit Engages the public in the pits and encourages them to ask questions 				
Feedback at Competition	Up to three points to be determined and awarded at the discretion of the Arena Chief, Pit Crew Chief and/or Mission Control Judges.			

Summary

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	Award	Maximum Points toward Joe Kosmo Award
On-site Mining in the Caterpillar Mining Arena	Required	First place \$3,000 & team scholarship Second place & \$2,000 team scholarship Third place \$1,000 & team scholarship Teams not placing 1 st , 2 nd , or 3 rd will receive one point per kilogram of BP-1 and/or icy regolith simulant (gravel) mined and deposited up to 10 points	25 20 15 Up to 10
Systems Engineering Paper	Required	\$500 team scholarship	Up to 20
Outreach Project Report	Required	\$500 team scholarship	Up to 20
Slide Presentation and Demonstration	Optional	\$500 team scholarship	Up to 20
Social Media and Public Engagement	Optional	\$500 team scholarship	Up to 12
Judges' Innovation Award	Optional	School trophy	
Efficient Use of Communications Power Award	Optional	School trophy	
Caterpillar Autonomy Award	Optional	First place \$1,500 team scholarship Second place \$750 team scholarship Third place \$250 team scholarship	
Joe Kosmo Award for Excellence	Grand Prize	School trophy and \$5,000 team scholarship	

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Required Elements

All items are due by 12:00 p.m. (noon) eastern time on the dates assigned, below, and failure to submit are grounds for disqualification. Please do not wait for the last minute, the last hour or even the last day to submit your items as this will overload the server and prevent receipt of your documents. Communicate ahead of the due dates with any potential issues.

REQUIRED

Registration Application*	First 50 teams are registered
Systems Engineering Paper	April 11, 2016
Outreach Project Report	April 11, 2016
On-Site Mining	May 18-20, 2016
Team Check-In	May 16, 2016 until 3:00 p.m.
Practice Days	May 16-17, 2016
Competition Days	May 18-20, 2016
Awards Ceremony	May 20, 2016 (evening)

OPTIONAL

Presentation File	April 22, 2016
Social Media and Public Engagement	All year

REQUIRED DOCUMENTATION

Letter of from University's Faculty Advisor	With Complete Application
Letter of from University's Dean of Engineering	November 30, 2015
Team Roster	November 30, 2015
Student Participant	November 30, 2015
Faculty Participation Form	November 30, 2015
Transcripts (unofficial copy is acceptable)**	November 30, 2015
Signed Media Release Form	November 30, 2015
Team Photo W/Faculty (high resolution.JPG required)	January 8, 2016
Team Biography (200 words maximum)	January 8, 2016
Corrections to NASA Generated Team Roster	February 8, 2016
Head Count Form	February 8, 2016
Final Team Roster (no changes after this date)	March 1, 2016
Rule 31 Documentation	April 22, 2016
Rule 32 Video	April 22, 2016
Shipping Bill of Lading/Commercial Invoice	April 22, 2016

OPTIONAL DOCUMENTATION

Student Resume	November 30, 2015
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*Registration is limited to one team per university campus and will end when NASA approves 50 team applications.

** Each student's Transcript must be from the university and show:

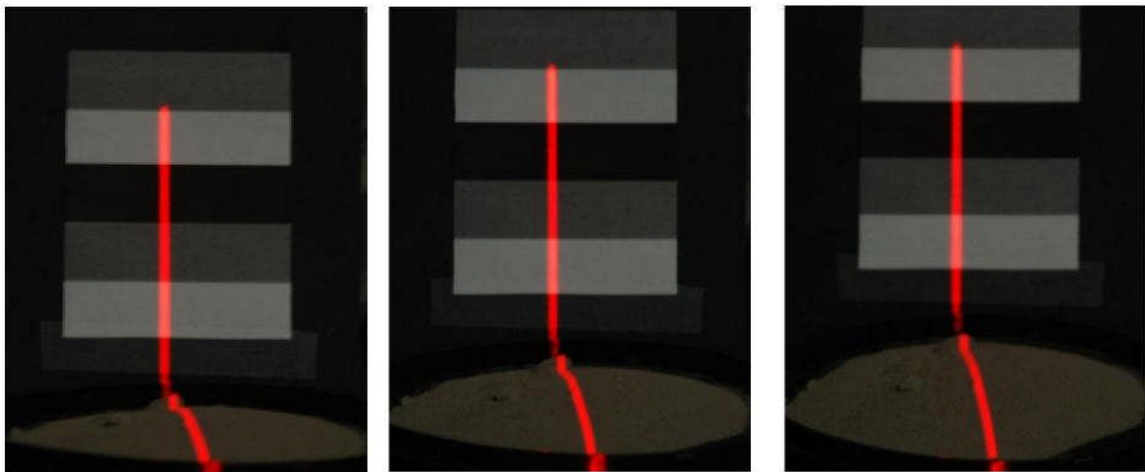
- Name of Student and Name of College / University
- Current student status within the 2015-2016 academic year
- Coursework taken and grades

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Definitions

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

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) – The coefficient of friction and the cohesion of Martian soil have not been precisely measured due to a lack of scientific data from Mars. 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 Martian soil.

- 1) It does not behave like sand.
- 2) There are naturally occurring rocks in the BP-1 aggregate.
- 3) The coefficient of friction has not been measured for BP-1.
- 4) Is a crushed lava basalt aggregate which is similar to Mars Volcanic Ash.
- 5) The density of the compacted BP-1 aggregate will be between 1.5 g/cm^3 and 1.8 g/cm^3 .
- 6) BP-1 behaves like a silty powder soil and most particles are under 100 microns in diameter.
- 7) Will be compacted and the top layer will be raked to a fluffy condition of approximately $.75 \text{ g/cm}^3$, similar to the Martian surface.
- 8) The study on BP-1 is available on <http://www.nasa.gov/nasarmc> "Soil Test Apparatus for Lunar Surfaces".

- 9) Dr. Philip Metzger, NASA Physicist (ret) and current University of Central Florida faculty member, describes BP-1 and its behavior at <http://youtu.be/hMfrv7mlxbE>.
- 10) Teams are encouraged to develop or procure simulants based on basaltic minerals and lunar surface regolith particle size, shape, and distribution.
- 11) BP-1 is not commercially available and it is made from crushed basalt fines.

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>.

Caterpillar Mining Arena – An open-topped container (i.e., a box with a bottom and 4 side walls), containing BP-1, within which the mining robot will perform each competition attempt. The inside dimensions of the each side of the Caterpillar Mining Arena will be 7.38 meters long and 3.88 meters wide, and 1 meter in depth. The BP-1 aggregate will be approximately .3 meters in depth and approximately .5 meters from the top of the walls to the surface. There is no guarantee that the BP-1 in the mining arena will have a level surface, since planetary surfaces are random and chaotic. Be prepared for slopes, irregularities and small rocks in the BP-1 simulant surface. The Caterpillar Mining Arena for the practice days and official competition will be provided by NASA. The Caterpillar Mining Arena will be outside in an enclosed tent. The Caterpillar Mining Arena lighting will consist of high intensity discharge (HID) lights such as metal halide lights inside a tent structure with clear sides, which is not quite as bright as outdoor daylight conditions. The atmosphere will be an air-conditioned tent without significant air currents and cooled to approximately 77 degrees Fahrenheit. See Diagrams 1 - 3. The Caterpillar Mining Arena steel, primer and paint specifications are as follows:

- 1) Steel: A-36(walls) & A-992(I-beams) structural steel.
- 2) Primer: Devran 201 epoxy primer, 2.0 to 3.0 mils, Dry Film Thickness (DFT).
- 3) Paint: Blue Devthane 379 polyurethane enamel, 2.0 to 3.0 mils, DFT (per coat).

Collector Bin – A Collector Bin in the Caterpillar Mining Arena for each competition attempt into which each team will deposit excavated BP-1. The Collector Bin will be large enough to accommodate each team's excavated BP-1. The Collector Bin will be stationary and located adjacent to the Caterpillar Mining Arena. See Diagram 3.

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 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 BP-1 and/or icy regolith simulant from the Caterpillar Mining Arena by the mining robot and deposit of BP-1 icy regolith simulant from the mining robot into the Collector Bin.

Gravel - This is intended to simulate icy-regolith buried on Mars. The gravel will be approximately 2 cm in diameter (minimum size) but will have random particle sizes larger than that also mixed into the gravel. The 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.

Mining robot – A tele-operated or autonomous robotic excavator in the Robotic Mining Competition 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 in the Robotic Mining Competition will be averaged to determine ranking in the on-site mining category.

Practice time – Teams will be allowed to practice with their mining robots in the Caterpillar Mining Arena. NASA technical experts will offer feedback on real-time networking performance during practice attempt. A maximum of two practice attempts will be allowed, but not guaranteed.

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 Caterpillar Mining Arena.

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 Caterpillar Mining Arena and 10 minutes for the mining robot to perform the functional task. Safe the robot and remove from the mining arena quickly and as directed by the mining judge.

Basaltic Regolith Properties

Since the properties of Mars regolith vary and are not well known, this competition will assume that Martian 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/

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End of Rules & Rubrics

(Rev 2.0, 01.08.2016)

