1. INTRODUCTION

1.1 LUNABOTICS

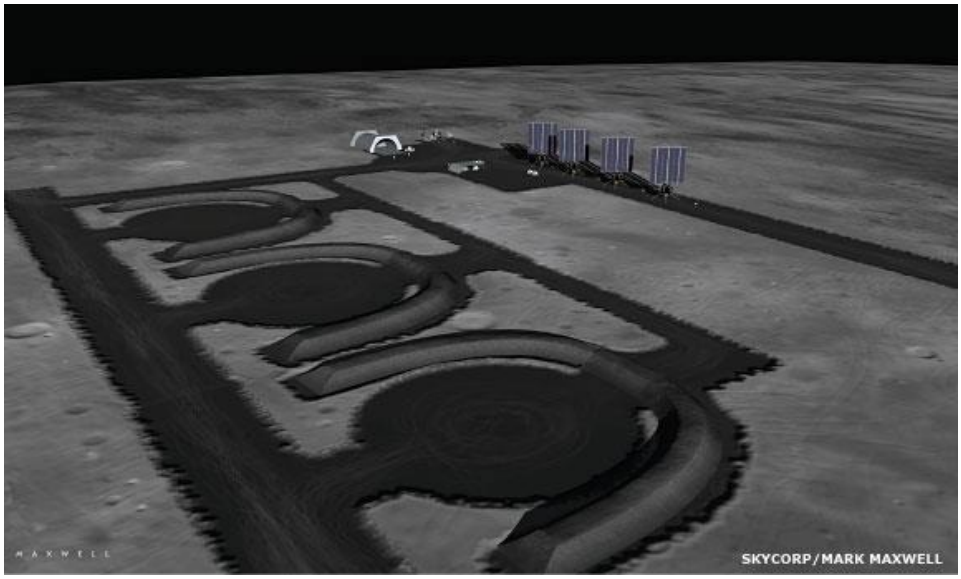
Provides accredited institutions of higher learning students (vocational-technical, college, university) an opportunity to apply the NASA Systems Engineering process to design and build a prototype robot capable of performing the proposed operations on a simulated Lunar regolith surface. NASA directly benefits from this challenge by annually assessing student designs and data in similar ways that it does for its own prototypes.

The skills students develop in Lunabotics apply to other high technology industries that rely on systems engineering principles. These industries will create a workforce posed to lead a new space-based economy and add to the economic strength of our country. Encouraging innovation in student designs increases the potential of identifying clever solutions to the many challenges inherent in future Artemis Lunar missions. Students will develop a deeper understanding and enhance their communication, collaboration, inquiry, problem-solving, and flexibility skills that will benefit them throughout their academic and professional lives.

Students on the team shall perform 100% of this project (including design, construction and task components of their vehicle and deliverables, and including performing or supervising work that is supported by a professional machinist for the purpose of training or safety).

1.2 Lunabotics 2024 and Beyond

The necessary lunar surface tasks are evolving to meet the NASA Artemis Mission requirements. In the past Lunabotics challenges we gathered data to support Lunar mining for consumables in the Lunar regolith. **Now the task is to gather data on Lunar construction by designing and building a robot that will traverse the chaotic Lunar terrain and <u>construct a regolith-based berm</u>**. The goal is to build a berm structure which would be useful to the Artemis Mission for blast and ejecta protection during lunar landings and launches, shading cryogenic propellant tank farms, providing radiation protection around a nuclear power plant and other mission critical uses.



Typical concept of Lunar Landing Pads with Berms (Source: NASA/ SkyCorp)

The Lunabotics 2024 Challenge consists of three events:

1.2.1 NASA's Lunabotics Project Development Challenge (contained within the separate KSC document).
1.2.2 University of Central Florida's (UCF) Lunabotics Qualification Challenge (contained within this document).
1.2.3 NASA's Lunabotics On-Site Challenge (contained within the separate KSC document).

The team's completing all the deliverables in the KSC Lunabotics challenge will be forwarded to UCF's Lunabotics Qualification Challenge. UCF will issue invitations to the teams from NASA's Lunabotics Project Development Challenge. UCF's Lunabotics Qualification Challenge– this is an on-site challenge to be held at the University of Central Florida (UCF) Florida Space Institute's Exolith Lab in Orlando, Florida. The arena is filled with Lunar Highlands Simulant (LHS-2E). The technical sheet for LHS-2E is referenced in Appendix A of this report. NASA's Lunabotics On-Site Challenge will issue invitations to the 10 highest scoring teams from UCF's Lunabotics Qualification Challenge.

NASA's Lunabotics On-Site Challenge - the top 10 scoring teams from the UCF Lunabotics Qualification Challenge will be invited to the Kennedy Space Center (KSC), Merritt Island, Florida to compete on-site in the Artemis Arena located in the Astronauts Memorial Foundation's Center for Space Education Building.

All teams that do not qualify for NASA's Lunabotics On-Site Challenge are invited to attend this challenge, watch the robotic runs, participate in educational seminars (Systems Engineering, Patent Applications, etc.) and tour the Kennedy Space Center Visitor Complex.

1.3 WHY THE MOON

NASA's human lunar exploration plans under the Artemis program call for sending the first woman and first person of color to the surface of the Moon and establishing sustainable exploration by the end of the decade. Working with U.S. companies and international partners, we will uncover new scientific discoveries and lay the foundation for private companies to build a sustainable lunar economy. The agency will use what we learn on the Moon to prepare for humanity's next giant leap – sending astronauts to Mars (https://www.nasa.gov/topics/moon-tomars/overview).

1.4 ACCREDITATION BOARD FOR ENGINEERING AND TECHNOLOGY (ABET)

One of the goals of Lunabotics is to introduce students to the ABET experience by aligning the events to those student outcomes. ABET is a nonprofit, ISO 9001 certified organization that accredits college and university programs in applied and natural science, computing, engineering and engineering technology. ABET accredits college and university programs in the disciplines of applied and natural science, computing, engineering and engineering technology at the associate, bachelor's and master's degree levels. ABET is the basis of quality for STEM disciplines all over the world. Schools do not have to be ABET accredited to participate (https://www.abet.org/).

CRITERIA 3. STUDENT OUTCOMES:
For baccalaureate degree programs, these student outcomes must include, but are not limited to, the following learned capabilities:

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

1.5 WAIVER

All team members must complete a waiver to attend the UCF competition. Please email lunabotics@ucf.edu for this form if you do not have it already.

1.6 ROLES AND RESPONSIBILITIES

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

1.7 CODE OF CONDUCT / APPEALS

Lunabotics is a National Aeronautics and Space Administration (NASA) Artemis Student Challenge and is held in a positive and safe environment. Competitors shall be professional, courteous and respectful to all individuals. Students and faculty shall conduct themselves with integrity as to the spirit and intent of the rules, rubrics and regulations. Violation of the intent of a rule is a violation of the rule itself. A team found in violation of the rules, rubrics, or exhibiting unsportsmanlike conduct may be disqualified from the challenge individually or as a team. All

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

1.8 FREQUENTLY ASKED QUESTIONS AND HELP

1.8.1 The team is responsible for monitoring the UCF Lunabotics Qualification Challenge for notices, updates, feedback requests and responses to FAQ's. The UCF Guidebook and the FAQ's shall be read together as one document. There will be no response to requests for information already contained in the Guidebook or to waive a deadline, rule or rubric. Communications to the UCF staff shall be through the advisor and/or team lead.

1.8.2 UCF will utilize Slack, an online communication system, for communication, questions, and announcements regarding the challenge. To locate the Slack as well as any additional information on the competition, please visit the Lunabotics page on Exolith Labs: Lunabotics Challenge - Florida Space Institute (ucf.edu)

1.8.3 Please email lunabotics@ucf.edu for any additional questions.

2. ELIGIBILITY, DELIVERABLES, TIMELINE & APPLICATION

2.1 ELIGIBILITY

2.1.1 Accredited institutions of higher learning (vocational / technical schools, colleges, universities, etc.) in the United States, its Commonwealths, territories and or possessions. Institutions may be permitted to have more than one team at Lunabotics.

2.1.2 Students shall: be 18 years old at registration on the NASA STEM Gateway portal, currently enrolled and in good standing with their school, be from the same school as their team, and can only participate on one team.

2.1.3 Teams shall: be composed of a minimum of 2 undergraduate students, graduate students, have its own working robot(s), and be accompanied by an adult employed by the accredited institution that shall accompany the team to UCF/KSC. The number of students on the team is at the discretion of the school. Students who have graduated in the same semester/quarter as this challenge are eligible to be on the team.

2.2 TIMELINE

Dates Are Subject to Change

TIMELINE	
Wed Sep 06, 2023	UCF Lunabotics Guidebook Released
Fri. May 10 – Wed. May 15, 2024	UCF's Lunabotics Qualification Challenge at the University of Central Florida (UCF) Florida Space Institute's Exolith Lab in Orlando, Florida
Wed May 15, 2024 - Fri May 17, 2024	NASA's Lunabotics Final Challenge at the NASA Kennedy Space Center, The Astronauts Memorial Foundation, Center for Space Education (CSE), Merritt Island, Florida

Statement of Supervising Faculty

A statement of support is required from a faculty/advisor indicating a willingness to supervise and work with the team during all stages of the activity. There will be no consideration for teams working without a faculty advisor.

3. ROBOTS

Components (i.e. electronic, mechanical, etc.) are not required to be space qualified for atmospheric, electromagnetic, thermal or Lunar environments.

3.1 ROBOT REQUIREMENTS

3.1.1 Robot(s) shall be contained within a payload envelope measuring 1.5m length x 0.75m width x 0.75m height with a maximum mass of 80kg. It may deploy or expand beyond the envelop after the start of each attempt but may not exceed 1.75m in additional height which is 2.5 m above the surface of the regolith. (these dimensions correspond to the typical payload volume available on today's Lunar landers that are commercially available). The commercial cost of delivering payloads to the Moon is about $1.2 Million per kg (estimate). This competition aims to simulate a Lunar mission where a robot is delivered to the Moon. This corresponds to an approximate mission cost of $72 Million. Lower masses will result in lower mission costs so this competition rewards teams that have a lower robot mass.

3.1.2 Robots shall have a central hoist point or sling system based around the robot's center of gravity (CG). The hoist point or sling system will allow the robot to be picked up by an overhead crane for placement into the arena.

3.1.3 Robots shall have a minimum of four (4) lifting points, safe for human hands and clearly marked (ISO 7000-1368) for students and NASA staff to use.

Teams are expected to coordinate with the arena judges for the placement and removal of their construction robot onto the LHS-2E surface. There must be one person per 20 kg of mass of the construction robot, requiring a minimum of four people to carry the maximum allowed mass of 80 kg Assistance will be provided if needed.

3.1.4 Robots will be inspected for the volume constraint in the stowed configuration during the Safety Inspection. A "jig" frame will be placed over the rover for volume constraint verification. No modifications or team robot interaction is permitted during this verification.

3.1.5 Multiple robot systems are allowed, but the total mass and starting dimensions of the whole system must comply within the volumetric dimensions given in this rule. subsystems on the robot used to transmit commands / data and video to the telerobotic operators are counted toward the mass limit. Equipment not on the robot used to receive data from and send commands to the robot for telerobotic operations is excluded from the mass limit.

3.1.6 The site preparation (SP) robot can separate itself intentionally, if desired, but all parts of the SP robot must be under the team's control at all times. The robot does not have to re-assemble prior to the end of the competition run.

3.1.7 The robot can run either by telerobotic (remote control) or in autonomous operations and cannot have any touch sensors to sense and avoid obstacles.

3.1.8 The launch volume dimensions of the robot may be oriented in any way (i.e. length, width, height - could be defined along any of the X, Y, Z axes) (dimensions correspond to the typical payload volume available on today's Lunar landers). The team must declare the robot orientation by length and width to the inspection judge.

3.1.9 Reference Point Arrow - must mark the forward direction of the mining robot in the starting position configuration (the reference location and arrow pointing forward can point any direction of the team's choosing, except up or down). The judges will use this reference point and arrow to orient the mining robot in the randomly selected direction and position (you can use a permanent-type marker) indicating the team's choice of forward direction on any location on the robot is acceptable if multiple arrows do not conflict. The arrow does not have to indicate the robot's preferred forward direction. The arrow is used only to orientate the robot prior to starting the robot run to face the robot arrow either north, east, south, or west after spinning the direction wheel.

3.1.10 Subsystems used to transmit commands / data and video to the telerobotic operators are counted toward the mass limit. Equipment not on the robot used to receive data from and send commands to the robot for telerobotic operations is excluded from the mass limit.

3.1.11 The "KILL SWITCH" - The robot shall be equipped with an easily accessible red emergency stop button or "Kill Switch" as follows: Use sound engineering practices and principles in placing the "Kill Switch" on your robot(s), failure to do so may result in a safety disqualification. The "Kill Switch" shall have a minimum diameter of 40 mm; it shall be located on the surface of the construction robot and require no additional steps to access it. Only one "Kill Switch" per robot and in the case of multiple robots, each robot will have its own "Kill Switch." It shall be easily accessible and activated in an easy and quick manner. Disabling the "Kill Switch" without authorization from the Staff shall result in a safety disqualification. The emergency stop button must stop the construction robot's motion and disable power with one push motion on the button. It must be highly reliable and instantaneous. For these reasons an unmodified "Commercial Off-The-Shelf" (COTS) red button is required. A closed control signal to a mechanical relay is allowed as long as it stays open to disable the robot. This rule exists in order to have the capability to safe the construction robot in the event of a fire or other mishap. The button should disconnect the batteries from all controllers (high current, forklift type button) and it should isolate the batteries from the rest of the active sub-systems as well. Only onboard laptop computers and data-logger(s) may stay powered on if powered by its own, independent, internal computer battery. For example: it is acceptable to have a small battery onboard that only powers a (ex:) Raspberry Pi (or equal) control computer, and whose power does not flow through the main robot kill switch.

3.1.12 The robot must provide its own onboard power. No facility power will be provided to the robot during the attempt. There are no power limitations except that the robot must be self-powered and included in the maximum mass limit. The energy consumed must be recorded with a "Commercial Off The-Shelf" (COTS) electronic data logger device. Actual energy consumed during each attempt must be shown to the judges on the data logger immediately after the attempt) The 'immediate' part refers to the judge climbing into the arena, finding the logger and recording the power reading. If the logger is independently powered, then the robot can be remotely powered off after the run. Although this is acceptable, it is not recommended in case the robot needs to be commanded to complete an operation so that it can be removed from the arena.

3.1.13 To ensure the robot is usable for an actual mission, it cannot employ any fundamental physical processes, gases, fluids or consumables that would not work in an off-world environment. For example, any dust removal from a lens or sensor must employ a physical process that would be suitable for the Lunar surface. Teams may use processes that require an Earth-like environment (e.g., oxygen, water) only if the system using the processes is designed to work in a Lunar environment and if such resources used by the robot are included in the mass of the robot. Closed pneumatic systems are allowed if the gas is supplied by the robot itself. Pneumatic systems are permitted if the gas is supplied by the robot and self-contained.

3.1.14 The rules are intended for robots to show an off-world plausible system functionality, but the components do not have to be traceable to an off-world qualified component version. Examples of allowable components are: Sealed Lead-Acid (SLA) or Nickel Metal Hydride (NiMH) batteries; composite materials; rubber or plastic parts; actively fan cooled electronics; motors with brushes; infrared sensors, inertial measurement units, and proximity detectors and/or Hall Effect sensors, but proceed at your own risk since LHS2E & BP-1 regolith simulant is very dusty and abrasive. Teams may use honeycomb structures as long as they are strong enough to be safe and the edges sealed to prevent dust intrusion, a wheel with a large honeycomb structures that is open on both sides is allowed as long as the edges are not so sharp that they would be a cutting hazard. Teams may not use GPS, rubber pneumatic tires; air/foam filled tires; open or closed cell foam, ultrasonic proximity sensors; or hydraulics because NASA does not anticipate the use of these on an off-world mission.

4. ROBOTIC OPERATIONS

4.1 The site preparation robot cannot be anchored at the beginning of the proof of life demonstration.

4.2 At the start of the competition run, the mining robot may not occupy any location outside the defined starting position in the regolith arena.

4.3 The site preparation robot must operate within the regolith arena; it is not permitted to pass beyond the confines of the outside perimeter of the arena or hit the walls during the demonstration.

4.4 The site preparation robot may not use any process that causes the physical or chemical properties of the regolith simulant to be changed or otherwise endangers the uniformity between competition attempts. The mining robot may not penetrate the regolith simulant surface with more force than the weight of the mining robot before the start of each competition attempt.

4.5 No ordnance, projectile, far-reaching mechanism, etc. may be used. The mining robot must move on the regolith simulant surface.

4.6 A fiducial target may be attached to the designated arena fiducial mount for navigation purposes only. The designated area is described in **Section 5.14**. This navigational aid system must be attached during the setup time and removed afterwards during the removal time.

4.7 The outline of the berm target area will be marked on the surface of the regolith and the coordinates of the berm target area with respect to the 0,0 origin point will be given in the final version of the guidebook.

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

4.9 The beacon may send a signal or light beam or use a laser-based detection system which have not been modified (optics or power). Only Class I or Class II laser or low powered lasers (< 5mW) are allowed. Supporting documentation from the laser instrumentation vendor must be provided to the responsible faculty member for "eyesafe" lasers.

4.10 Inertial measurement units (IMU) are allowed on the robot. Teams have to explain in the Proof of Life video how the compass feature will be switched off or how the compass data is subtracted to ensure the internal calculations do not make use of the compass (from any magnetic field surrounding the robot). The Moon does not have a consistent magnetic field.

4.11 Global Positioning Satellite (GPS) or IMU-enabled GPS devices are not allowed. Teams have to explain in the Proof of Life video how the device will be switched off or the data is subtracted and ensure the internal calculations do not make use of the GPS or IMU-enabled GPS device.

4.12 Autonomous robot operations are highly encouraged but not required.

5. EXOLITH ARENA SPECIFICATIONS

5.1 The Exolith Arena at UCF is filled with SRT Lunar Highlands Simulant (LHS-2E) crushed anorthosite and basalt rock lunar regolith simulant. The technical data sheet for this simulant can be found in Appendix A or on the Space Resource Tech website: (LHS-2E) Engineering Grade Lunar Highlands Simulant – Space Resource Technologies

5.2 The competition area within the arena measures ~8.14m long and ~4.57m wide.

5.3 The arena contains ~1m depth of LHS-2E

5.4 Surfaces will consist of craters in the obstacle and excavation zones of the arena with randomly placed obstacles. The robot will be placed in the starting zone of the arena in a randomly selected starting position and direction.

5.5 There will be at least four (4) boulder obstacles placed on top of the LHS-2E surface within the obstacle zone area before each competition attempt is made.

5.6 The placement of the boulder obstacles will be randomly selected before the start of the competition. The boulder obstacles will be buried and cannot be moved.

5.7 Each obstacle may have a diameter of approximately 20 cm to 40 cm and will have random heights.

5.8 There will be at least three (3) craters of varying depth and width, being no wider or deeper than 40 – 50 cm in the obstacle zone

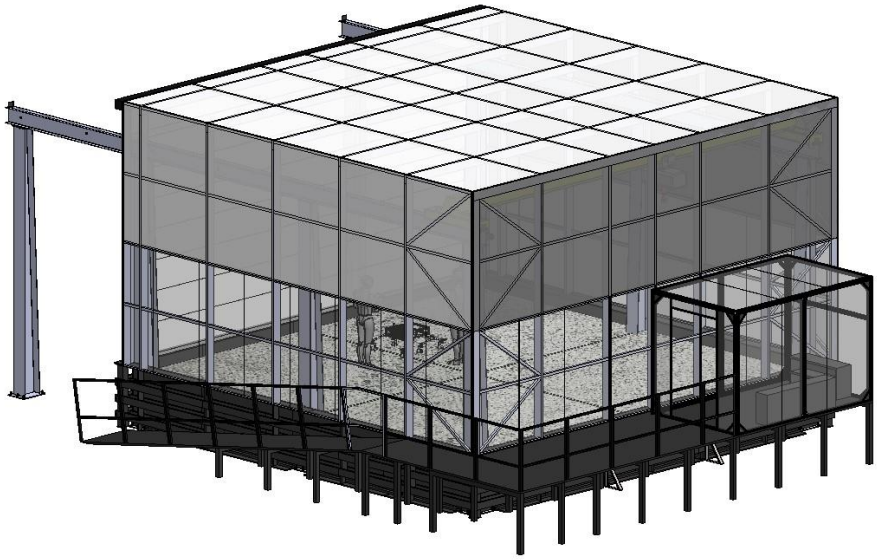
5.9 There will be at least three (3) boulder obstacles placed on top of the LHS-2E surface within the excavation zone area before each competition attempt is made.

5.10 The placement of the boulder obstacles will be randomly selected before the start of the competition. The boulders in the excavation zone <u>will not be buried</u> and may be pushed to the side of the arena.

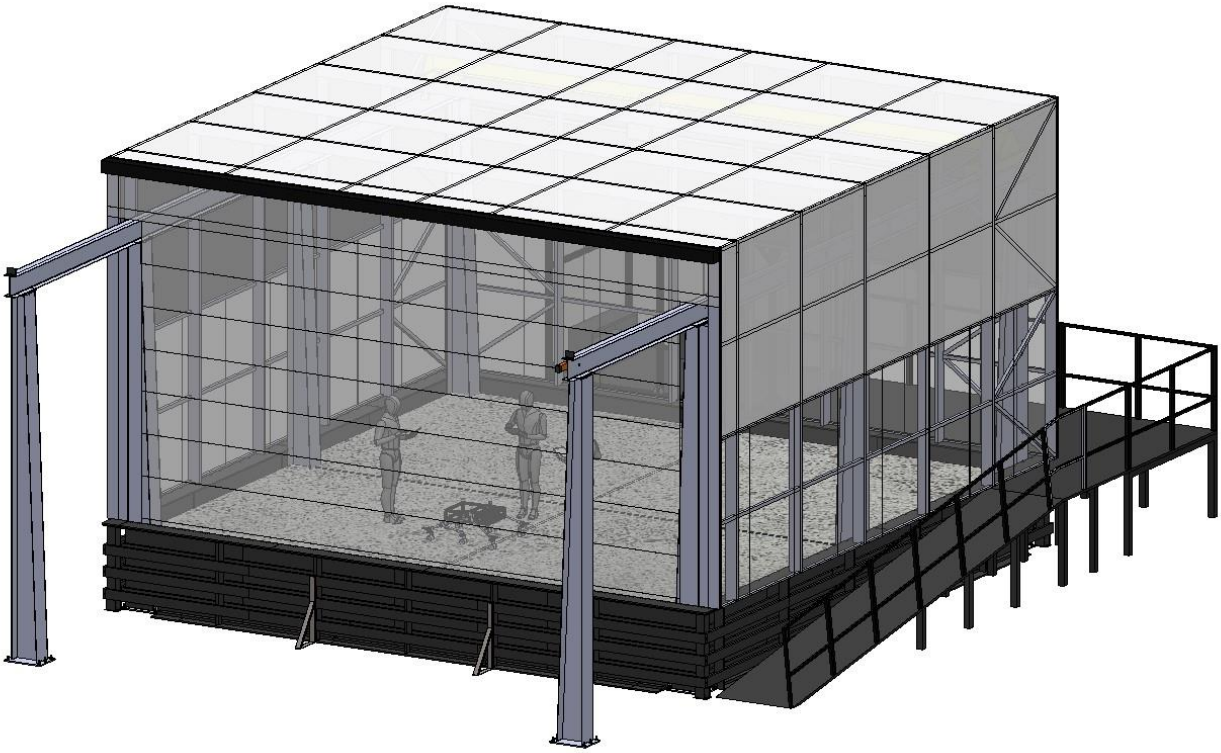
5.11 Each obstacle may have a diameter of approximately 20 cm to 40 cm and will have random heights.

5.12 There will be at least one (1) crater, being no wider or deeper than 40 – 50 cm in the excavation zone. These craters may be filled in with regolith simulant.

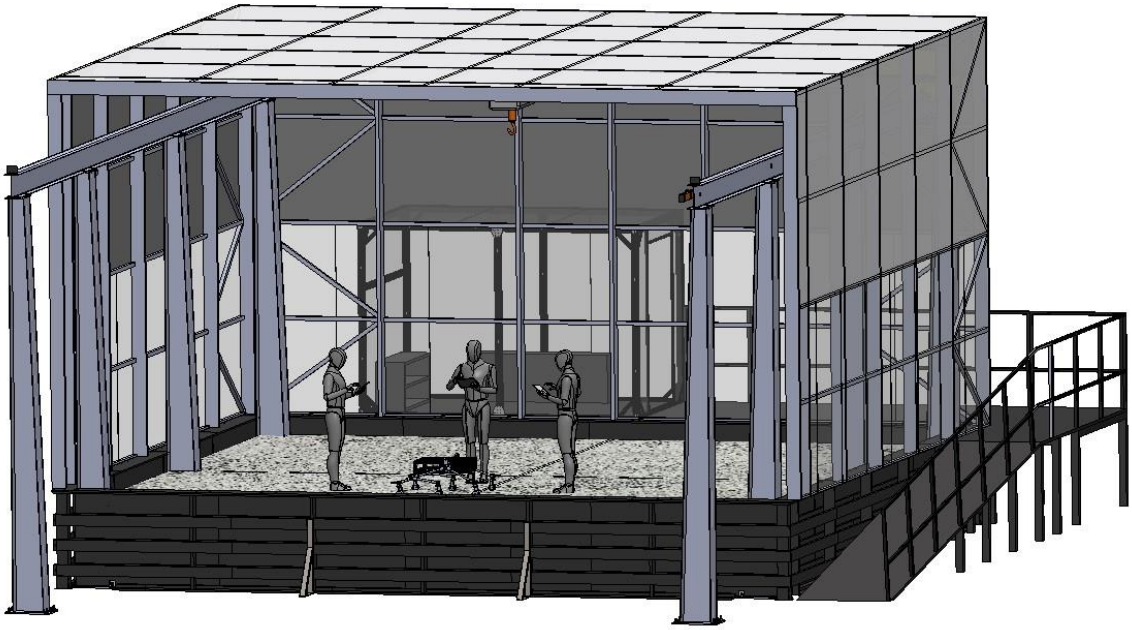
5.13 There are six crane legs located within the regolith bin. The legs are located at each corner of the bin, as well as the center of both the North and South wall.



UCF Arena (NW Corner)



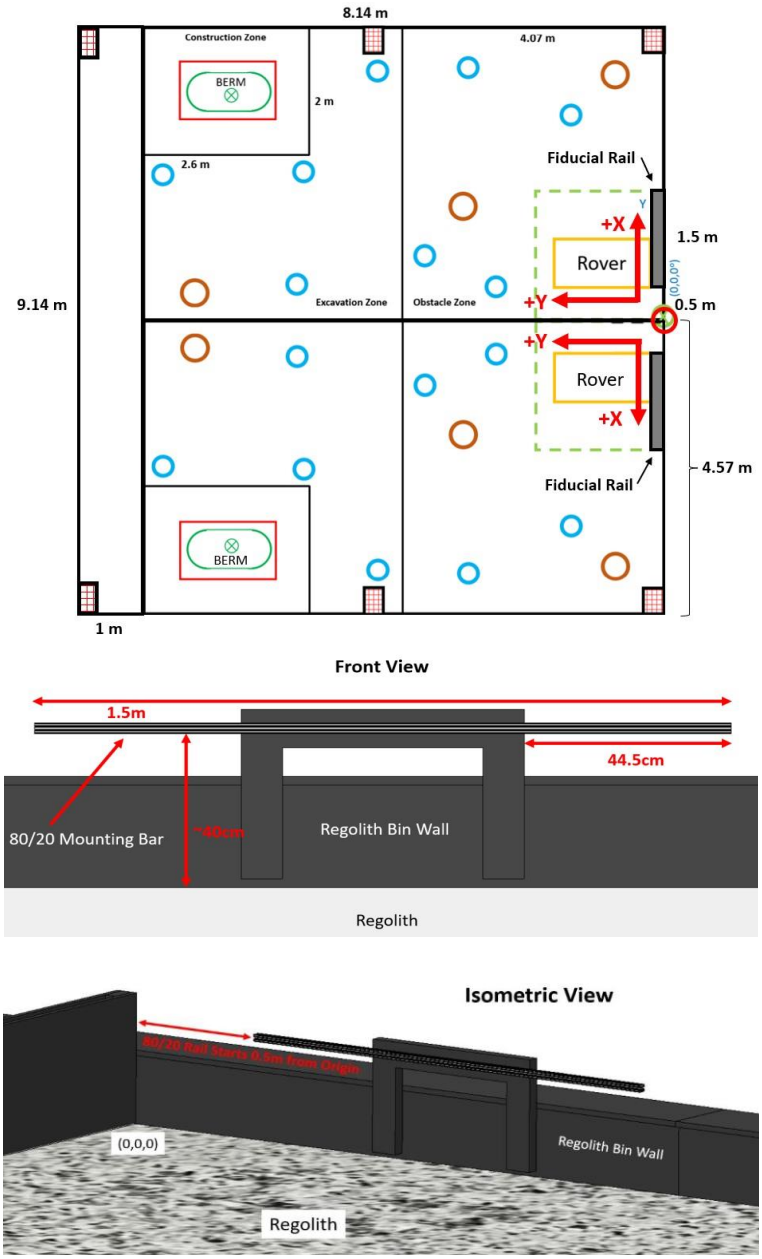
UCF Arena (NE Corner)



UCF Arena (East Side View)

5.14 Mounting of Beacons for Navigation

Navigation beacons can be mounted using the 1.00" x 1.00" 80/20 secured to the front surface of the regolith bin perimeter wall. The 80/20 will be mounted at a height approximately 40 cm (+/- 2.5cm) above the regolith surface. The origin point is the intersection where the barrier separating the two arenas meets the regolith bin perimeter wall (marked as a red circle in Figure 1). The fiducial mounting rail will be 0.5 meters from the origin and will extend an additional 1.5 meters.



The 80/20 will be matte black to avoid reflections that might impact various navigational systems. The part number is 1010-Black representing the 1.00" X 1.00" T-Slotted profile with 4 open T-slots. The Tslots on the top, front, and bottom of the 80/20 should be available for mounting over the full length of the bar. The T-slots on the back of the bar should be available for mounting using the part of the bar

that extends past the vertical support on both ends. Figure 4 shows the details of the 80/20 and its profile.

6. LUNAR SITE PREPARATION & BULK REGOLITH BERM CONSTRUCTION CATEGORY

6.1 The Lunabotics Challenge at Exolith lab, UCF, Florida.

Lunar bulk regolith construction requires teams to consider several design and operation factors such as high robot dust tolerance and minimizing dust projection, efficient communications, minimizing vehicle mass, minimizing energy/power required, and maximize autonomy. In each of the two official competition attempts, the teams will score cumulative construction points. The teams with the first, second and third most construction points averaged from both attempts will receive 25, 20 and 15 points, respectively. Teams not winning first, second or third place in the construction category can still earn one bonus point for each 0.10 cubic meters of berm constructed up to a maximum average of ten points. The top 10 teams will be moving onto testing at KSC.

6.2 SCORING

Construction Points Calculator – Artemis Arena				
Construction Category Elements	**Units**	**Specific Points**	**Example Actuals**	**Example Construction Points**
1. ***Pass All Inspections (Comm/Vehicle)***.	1,000=Pass / 0=Fail	0 or 1,000	1,000.00	**1000.00**
2. ***Berm Construction*** – A volumetric scan before and after the run will be performed. Only the berm volume within the target berm location will be counted. The team will earn 5000 construction points for each cubic meter of berm constructed above grade.	cubic meters m^3	5000	0.06	**300.00**
3. ***Camera bandwidth Use*** - During each competition attempt, the team will lose 200 pts for each situational awareness camera used (camera and width usage 200 kb/camera).	Kpbs/camera	-200.00	400.00	**-8.00**
4. ***Construction Robot Mass*** - During each competition attempt, the team will lose 8 Construction points for each kilogram of total construction robot mass. (For example, a construction robot that weighs 80 kg will lose 640 Construction points)(-8/kg).	kg	-8.00	80.00	**-640.00**

5. ***Report Energy Consumed*** - During each competition attempt, the team will lose one (1) Construction point for each watt-hour of energy consumed. The electrical energy consumed must be displayed by an (commercial off the shelf or "COTS") electronic data logger and verified by a judge (-1/watt-hour).	watt-hour	-1.00	9.00	**-9.00**
Dust Tolerant – see below				
Dust Free – see below				
8. *Autonomy* - See Construction Points – Autonomy	task	75, 150, 175, 250, 325, 400, or 500	250.00	**250.00**
9. *Total Points*				**893.00**

6.3 CONSTRUCTION POINTS

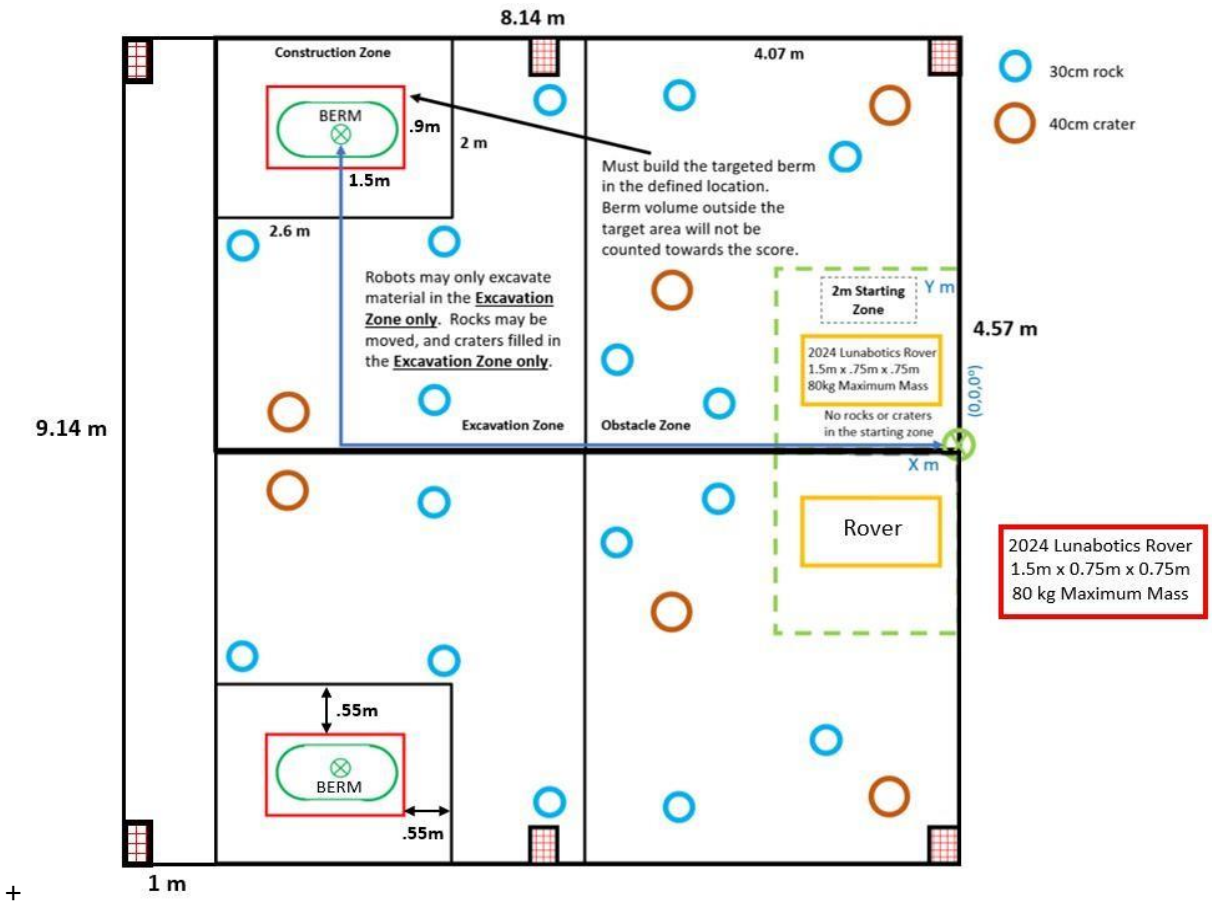


Figure 1. Exolith Arena Layout 1 – Starting Location

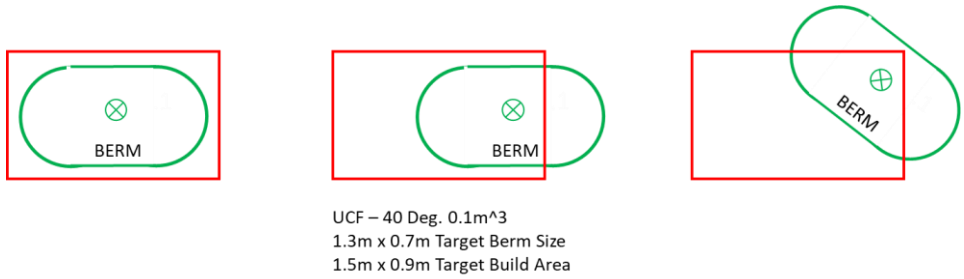


Figure 2. Exolith Arena Layout 2 - Berm Dimensions

Only the green actual berm volume inside the red box will count towards the berm volume measurement.

6.3.1 Each team will earn 1000 Construction points after passing the safety inspection and communications check.

6.3.2 During each competition attempt, the team will earn 5,000 Construction points for each cubic meter of berm constructed above grade. (For example, 0.06 cubic meters of berm constructed will earn 300 Construction points). Only the portions of the constructed berm within the target area for berm placement will be counted. The target area has perimeter dimensions of 1.5 m x 0.9 m.

6.3.3 During each competition attempt, the team will lose one (1) construction point for each 50 kilobits/second (kb/s) of average data used.

6.3.4 During each competition attempt, the team will lose 200 points for each situational awareness camera used (Camera Bandwidth Usage 200 kb/camera).

6.3.5 During each competition attempt, the team will lose 8 Construction points for each kilogram of total construction robot mass. (For example, a construction robot that weighs 80 kg will lose 640 Construction points).

6.3.6 During each competition attempt, the team will lose one (1) Construction point for each watt-hour of energy consumed. The electrical energy consumed must be displayed by an (commercial off the shelf or "COTS") electronic power data logger and verified by a judge.

6.3.7 DUST-TOLERANT DESIGN (BP1 Arena Only)
The 30 points for dust-tolerant design will be broken down as follows:

1. Drive train and components enclosed/protected: 10 points
2. Active dust control (brushing, electrostatics, etc.): 10 points
3. Custom dust sealing features (bellows, seals, etc.): 10 points

6.3.8 DUST-FREE OPERATION (BP1 Arena Only)
During each competition attempt, a team can earn up to 70 Construction Points for dust free operation. The judges will allocate these points based on actual performance during the competition attempts. (If the construction robot has exposed mechanisms where dust could accumulate during a lunar mission and degrade the performance or lifetime of the mechanisms, then fewer Construction points will be earned in this category. If the construction robot raises a substantial amount of airborne dust or projects it due to its operations, fewer construction points will be earned. Ideally, the construction robot will operate in a clean manner, without dust projection, and all mechanisms and moving parts will be protected from dust intrusion. The construction robot will not be penalized for airborne dust while dumping into the berm footprint area. All decisions by the judges are final. The 70 points for dust-free operation will be broken down as follows:

1. Driving without dusting up crushed basalt (20 points)
2. Digging without dusting up crushed basalt (30 points)
3. Transferring crushed basalt without dumping the crushed basalt on your own robot (20 points)

7. COMMUNICATION POINTS

7.1 Each team is required to command and monitor their construction robot over the NASA/UCF provided network infrastructure.

7.2 This configuration must be used for teams to communicate with their robot.

7.3 The "Lander" camera is staged in the Construction Arena. Lander Control and camera display will be located with the team in the Mission Control Center (MCC).

7.4 The MCC will have an official timing display. The berm volume will be displayed after the end of the competition run.

7.5 Handheld radios will be provided to each team to link their Mission Control Center team members with their corresponding team members in the construction arena during setup.

7.6 Each team will provide the wireless link (access point, bridge, or wireless device) to their construction 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 construction robot and their control computers, through their own wireless link hosted in the Construction arena.

7.7 In the construction 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.

7.8 The network drop in the Construction arena will be elevated high enough above the edge of the regolith bed wall to provide adequate radio frequency visibility of the Construction arena.

7.9 A shelf will be set up next to the network drop at a height 0 to .5 meter above the walls of the arena and will be placed on the outside corner where the rover starts its operation. 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 construction robot.

7.10 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.

7.11 The WAP shelves for side A and side B of the Construction arena will be at least 6 meters apart to prevent electromagnetic interference (EMI) between the units.

7.12 Power Interfaces

7.12.1 NASA/UCF will provide a standard US National Electrical Manufacturers Association (NEMA) 5-15 type, 110 VAC, 60 Hz electrical jack by the network drop. This will be no more than 1.5 meters from the shelf.

7.12.2 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.

7.13 During the setup phase, the teams will set up their access point and verify communication with their construction robot from the Mission Control Center.

7.14 The teams must use the USA IEEE 802.11b, 802.11g, or 802.11n standards for their wireless connection (WAP and rover client).

7.15 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.

7.15.1 Encryption is not required, but it is highly encouraged to prevent unexpected problems with team links.

7.15.2 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.

7.16 Teams must be able to use and switch between channel 1 and channel 11 for the competition within 15 minutes of being notified to accommodate real-time scheduling changes.

7.17 Each team will be assigned an SSID that they must use for the wireless equipment for channel 1 and channel 11.

7.17.1 Teams SSID will be "Team_##."

7.17.2 Teams are required to broadcast their SSID.

7.18 The use of specific low power (these power consumers are not part of the total power consumed COTS meter) Bluetooth transmission equipment in the 2.4 GHz range is allowed for sensors and other robot communications. Bluetooth is allowed only at power levels of Classes 2, 3, and are limited to a maximum transmit power of 2.5 mW EIRP. Class 1 Bluetooth devices are not allowed.

7.19 The use of 2.4 GHz ZigBee technology is prohibited because of the possibility of interference with the competition wireless transmissions.

7.20 Technology that uses other ISM non-licensed radio frequencies outside of the 2.4 GHz range, such as 900 MHz and 5 GHz, are allowed for robot or sensor systems, but these frequencies will not be monitored during the competition. Interference avoidance will be the responsibility of the Team and will not be grounds for protest by any team.

7.21 Radio Frequency Power:

7.21.1 All Team-provided wireless equipment shall operate legally within the power requirements set by the FCC for Unlicensed Wireless equipment operating in the ISM radio band. The FCC Federal Regulations are specified in the Electronic Code of Federal Regulations, Title 47, Telecommunication, Part 15, and must be followed if

any commercial equipment is modified. All unmodified commercial off the shelf access point equipment and computers already meet this requirement.

7.21.2 If a team inserts any type of power amplification device into the wireless transmission system, this will likely create a violation of FCC rules and this is NOT allowed in the competition.

7.21.3 This radio frequency power requirement applies to all wireless transmission devices at any ISM frequency.

7.22 Data Utilization Bandwidth Constraints

7.22.1 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.

7.22.2 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.

7.23 For every kg of robot mass, a typical commercial lunar lander vendor will allow 10 kbps bandwidth. Higher bandwidth will result in additional mission costs. All teams are encouraged to stay within this bandwidth allocation and the judges will assess this metric as part of the Communications bandwidth prize.

7.24 Radio Frequencies and Communications Approval

7.24.1 Each team must demonstrate to the communication judges that their construction robot and access point are operating only on their assigned channel. Each team will have approximately 15 minutes at the communication judges' station.

7.24.2 To successfully pass the communication judges' station, a team must drive their construction robot by commanding it from their construction 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.

7.24.3 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.

7.24.4 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.

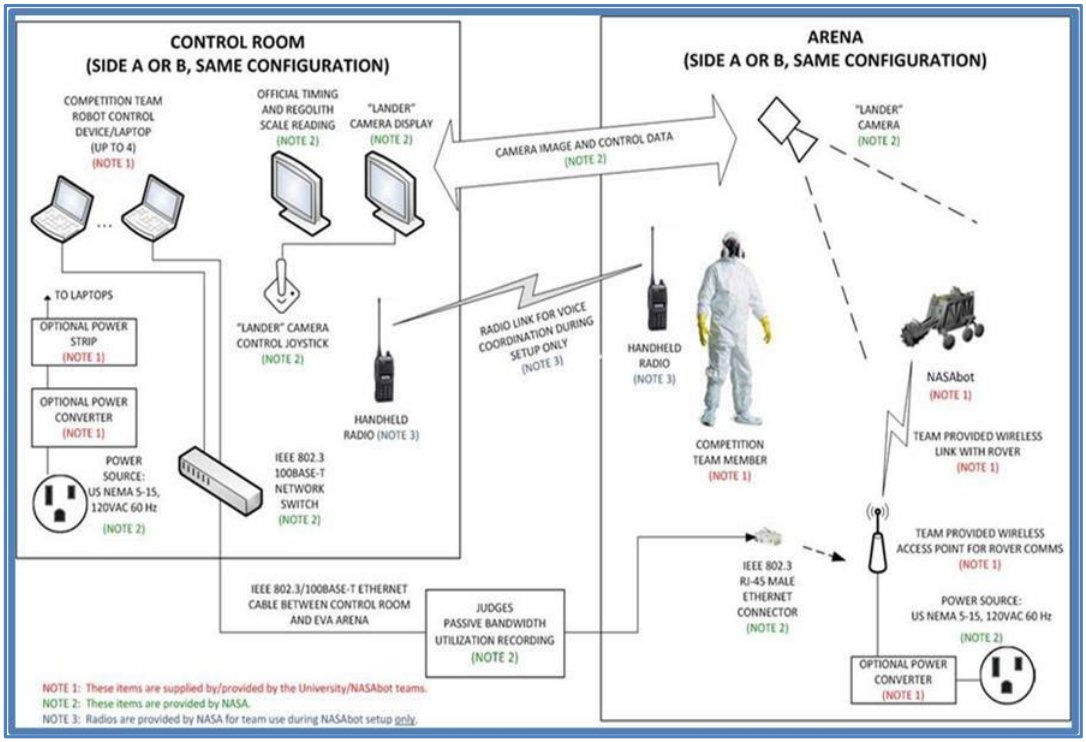
7.25 If a team cannot demonstrate the above tasks in the allotted time, the team will be disqualified from the competition.

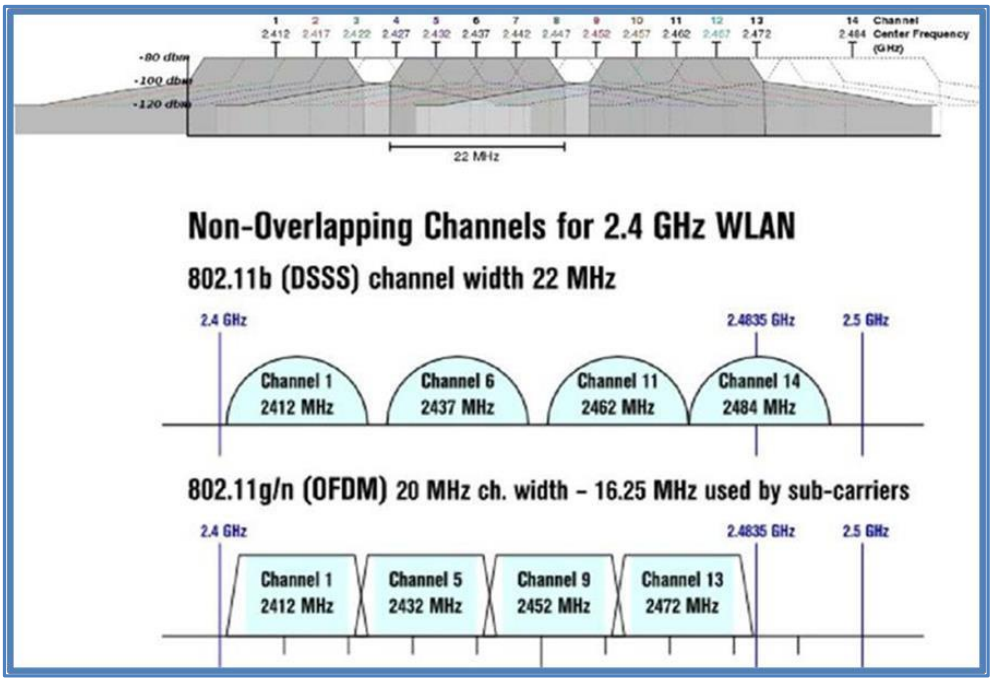
7.26 The teams will be able to show the communication judges their compliance with the rules.

7.27 The NASA communications technical experts will be available to help teams make sure that they are ready for the communication judges' station.

7.28 Once the team arrives at the communication judges' station, the team can no longer receive assistance from the NASA communications technical experts.

7.29 If a team is on the wrong channel during their competition attempts, the team will be disqualified and required to power down.





8. AUTONOMY POINTS

AUTONOMOUS OPERATION - During each competition attempt, the team will earn up to 500 Construction points for autonomous operation. As Mission Control Judges (MCJ) are not intimately familiar with each robot's concept of operations (ConOps) procedures, it is the sole responsibility of the team members in the control room to coordinate with and inform the MCJ of each attempt for autonomy points to make sure their autonomous attempts are recognized and therefore scored correctly. In each of the two official competition attempts, the teams will score cumulative autonomy points towards the **Caterpillar Autonomy Award**. Construction points will be awarded for successfully completing the following activities autonomously:

8.1 Excavation Automation: 75 pts

a) Teams are allowed to traverse to the Excavation Zone via remote control.
b) Once in the Excavation zone they need to indicate to the MCJ that they are going hands free for the excavation attempt.
c) The robot must execute machine control commands itself during the excavation task.
d) The robot must demonstrate the ability to dig regolith and reach a point to be able to transport regolith. Hands free operation must begin before the robot engages the regolith to begin the excavation process. Some examples
   1. Blade type implement – Start with the blade just above the surface and then hands free the robot would make an excavation cut loading the blade with material. The team can then take back remote-control and "carry" the material across the terrain surface. Carry means the blade height is kept basically at the height of the terrain so the material in front of the blade does not flow under the blade and is lost as the robot progresses forward.
   2. Bucket type implement - Start with the bucket just above the surface and then hands free the robot would make an excavation cut loading the bucket with material. Bucket must be completely removed from the regolith before returning to remote-control operation.
   3. Auger type implement - Start with the auger just above the surface and then hands free the robot would make an excavation cut loading the auger with material. Auger must be completely removed from the regolith before returning to remote-control operation.

e) Regolith must be excavated for the robot to transport to the construction zone per the robot's design. Successful regolith excavation for robot transport will be at the MCJ judgement (the intent is to show that the robot can excavate regolith and be prepared to transport regolith with completely hands-free operation). MCJ may engage the arena judges for confirmation if camera angle/performance does not allow confirmation in Mission Control.
f) Once excavation is complete the team must indicate they are going to remote control before taking control.
g) This level of automation will require teams to master the lower-level machine control of their robot platform associated with excavation. It is noted that past teams have proven this capability to be helpful in achieving better excavation results, as the coordination of the robot for excavation can be difficult to master.

8.2 Dump Automation: 75 pts

a) Teams are allowed to transport regolith after excavation to the construction zone via remote control.
b) The team must go into autonomous operation immediately after crossing (the front wheels or front of tracks) the boundary between the excavation and construction zones. The intent is that there is not any remote-control operation in the construction zone allowing the operator to "align" the robot to the berm construction location. The remote operator needs to coordinate communication with the MCJ to show hands-free operation when entering the construction zone.
c) The robot must align, approach, stop, and place regolith at the berm construction location. A discernable amount of regolith must be place at the berm location as determined by the MCJ. MCJ may engage the arena judges for confirmation if camera angle/performance does not allow confirmation in Mission Control.
d) This level of automation will require the team to master localization in the construction zone as well as path planning to align and place regolith at the designated berm construction location. Also, lower-level machine control of the robot for regolith placement will be mastered.

8.3 Travel Automation: 175 pts

Teams may begin in remote control and move the robot within the starting zone only in order to lock in their localization solution. The teams must then indicate to the MCJ that they are going into hands free mode while still in the starting zone. The robot must remain in hands free mode while crossing the obstacle field and crossing into the excavation zone. The robot must start in the starting zone and remain hands free until any part of the robot has crossed into the excavation zone (as determined by the MCJ) This level of automation will require the team to master the following:

a. Localization across the entire competition arena
b. Object detection and location relative to the robot
c. Navigational planning based on location and obstacles/traversable area
d. The competition judges will attempt to construct the obstacle field in such a way as to require obstacle detection, mapping, and navigation planning to determine a "slalom" route to reach the excavation zone. The teams should not architect a "Point and traverse" approach for this automation step.
e. If the robot moves a rock or drives across a crater in the obstacle zone, as determined by the MCJ/Arena judges, a 35 point reduction will be applied.
f. For maximum points the attempt must be made at the start of the run when first leaving the starting zone. In order to discourage the approach of "bread crumbs", a penalty of 50 points will be applied to any attempt that occurs after the traversing the obstacle zone in remote control.
g. If attempting excavation automation in coordination with travel automation the robot must remain in "hands free" control during travel and excavation.

Example: Robot cross the obstacle course in remote control before the attempt and hits an obstacle and drives across a crater during the attempt. 175 points – 50 – 35= 90 points.

8.4 Full Autonomy (One cycle): 400 pts

a. The robot must be in hands free control for one entire cycle
b. Teams may begin in remote control and move the robot within the starting zone only to localize. Teams must begin with hands free control from the starting area and remain in hands free mode while crossing the obstacle field and crossing into the excavation zone. Remaining in hands free control the robot must excavate regolith, transport to the berm construction location within the construction zone, and place/dump the regolith at the berm construction location. A discernable amount of regolith, as determined by the MCJ/Arena judges must be dumped at the berm construction location.
c. If the robot moves a rock or drives across a crater, as determined by the MCJ/Arena judges, a 35 point reduction will be applied. This is only true in the obstacle zone. The robot is allowed to move rocks and fill in craters in the excavation zone.
d. For maximum points the attempt must be made at the start of the run when first leaving the starting zone. In order to discourage the approach of "bread crumbs", a penalty of 50 points will be applied to any attempt that occurs after the traversing the obstacle zone in remote control.
e. This level requires mastery of all aspects of autonomy associated with this competition.

Example: Robot cross the obstacle course in remote control before the attempt and hits an obstacle and drives across a crater during the attempt. 400 points – 50 – 35= 315 points.

8.5 **Full Autonomy: 500 pts**

a. The robot must be in hands free control for all of the competition run completing two or more cycles of excavation and placement at the berm construction location of regolith. Berm construction points as determined by the volumetric scan must be achieved for this level of autonomy.
b. If the robot moves a rock or drives across a crater, as determined by the MCJ/Arena judges, a 35 point reduction will be applied. This is only true in the obstacle zone. The robot is allowed to move rocks and fill in craters in the excavation zone.
c. This level requires mastery of all aspects of autonomy associated with this competition and demonstrates a level of robustness to complete at least two full cycles. System robustness is essential for terrestrial and extra-terrestrial construction.

Example: Robot hits an obstacle and drives across a crater during the attempt. 500 points – 35 - 35 = 430 points.

8.6 Autonomous Operations Scoring

Sample Autonomous Operations Scoring						
	Excavation	Dump	Travel	Full – One Cycle	Full Autonomy	Total
Ex: 1	75	-	-	-	-	75
Ex: 2	-	75	-	-	-	75
Ex: 3	75	75	-	-	-	150
Ex: 4	-	-	175	-	-	175
Ex: 5	75	-	175	-	-	250
Ex: 6	-	75	175	-	-	250
Ex: 7	75	75	175	-	-	325
Ex: 8	-	-	-	400	-	400
Ex: 9	-	-	-	-	500	500

30

Any three successful completions of the Excavation, Dump, and Travel attempts will be combined for scoring. These could occur over separate passes within the run. Points will only count for one successful completion – i.e., you can only get 75 points for excavation automation even if you use it for every pass of the run.

9. CONSTRUCTION ARENA PROTOCOL

9.1 CONSTRUCTION ROBOT REQUIREMENTS

9.1.1 Student teams are expected to design, construct and test their own robots, students shall do 100 percent of the work. Reuse of structure and systems shall be identified and explained in the Systems Engineering Paper and Slide Presentation and Demonstration. It is the teams' responsibility to demonstrate to the judges they have met this requirement.

9.1.2 The construction robot can run either by telerobotic or autonomous operation.

9.1.3 The UCF Arena dimensions: ~ 8.14 m x 4.57 m footprint

9.1.4 The robot shall:

- have a maximum mass of 80kg.
- be contained within a payload envelope of 1.50 m x 0.75m x 0.75m (these dimensions correspond to the typical payload volume available on today's Lunar landers that are commercially available)
- the orientation of these dimensions may be chosen by each team for their specific design
- subsystems on the robot used to transmit commands / data and video to the telerobotic operators are counted toward the mass limit. Equipment not on the robot used to receive data from and send commands to the robot for telerobotic operations is excluded from the mass limit.
- may deploy or expand beyond the envelop after the start of each competition attempt but may not exceed a 1.5 m initial height and the deployed height must be lower than the ceiling height, which is 2.5 m above the surface of the regolith.

- The commercial cost of delivering payloads to the Moon is about $1.2 Million per kg (estimate). This competition aims to simulate a Lunar mission where a robot is delivered to the Moon. This corresponds to an approximate mission cost of $72 Million. Lower masses will result in lower mission costs so this competition rewards teams that have a lower robot mass.

9.1.5 Multiple robot systems are allowed but the total mass and starting dimensions of the whole system must comply with the volumetric dimensions given in this rule.

9.1.6 KILL SWITCH - The robot must be equipped with an easily accessible red emergency stop button or "Kill Switch." Use good engineering practices and principles in placing the "Kill Switch" on your robot(s), failure to do so may result in a safety disqualification. The "Kill Switch" shall have a minimum diameter of 40 mm; it shall be located on the surface of the construction robot and require no additional steps to access it. Only one "Kill Switch" per robot and in the case of multiple robots, each robot will have its own "Kill Switch." It shall be easily accessible and activated in an easy and quick manner. Disabling the "Kill Switch" without authorization from the Competition Staff shall result in a safety disqualification. The emergency stop button must stop the construction robot's motion and disable power with one push motion on the button. It must be highly reliable and instantaneous. For these reasons an unmodified "Commercial OffThe-Shelf" (COTS) red button is required. A closed control signal to a mechanical relay is allowed as long as it stays open to disable the robot. This rule exists in order to have the capability to safe the construction robot in the event of a fire or other mishap. The button should disconnect the batteries from all controllers (high current, forklift type button) and it should isolate the batteries from the rest of the active sub-systems as well. Only onboard laptop computers and data-logger(s) may stay powered on if powered by its own, independent, internal computer battery. For example: it is acceptable to have a small battery onboard that only powers a Raspberry Pi control computer, and whose power does not flow through the main robot kill switch.The robot must provide its own onboard power. No facility power will be provided to the robot during the competition runs. There are no power limitations except that the robot must be self-powered and included in the maximum mass limit. The energy consumed must be recorded with a "Commercial Off-The-Shelf" (COTS) electronic data logger device. Actual energy consumed during each competition run must be shown to the judges on the data logger immediately after the competition attempt) The 'immediate' part refers to the judge climbing into the arena, finding the logger and recording the power reading. If the logger is independently powered, then the robot can be remotely powered off after the run. Although this is acceptable, it is not recommended in case the robot needs to be commanded to complete an operation so that it can be removed from the arena.

9.1.7 To ensure the robot is usable for an actual mission, it cannot employ any fundamental physical processes, gases, fluids or consumables that would not work in an off-world environment. For example, any dust removal from a lens or sensor must employ a physical process that would be suitable for the Lunar surface. Teams may use processes that require an Earth-like environment (e.g., oxygen, water) only if the system using the processes is designed to work in a

Lunar environment and if such resources used by the robot are included in the mass of the robot. Closed pneumatic systems are allowed if the gas is supplied by the robot itself. Pneumatic systems are permitted if the gas is supplied by the robot and self-contained.

9.1.8 Components (i.e. electronic and mechanical) are not required to be space qualified for Lunar or atmospheric, electromagnetic, and thermal environments. Since budgets are limited, the competition rules are intended to require robots to show an off-world plausible system functionality, but the components do not have to be traceable to an off-world qualified component version. Examples of allowable components are: Sealed Lead-Acid (SLA) or Nickel Metal Hydride (NiMH) batteries; composite materials; rubber or plastic parts; actively fan cooled electronics; motors with brushes; infrared sensors, inertial measurement units, and proximity detectors and/or Hall Effect sensors, but proceed at your own risk since BP-1/LHS-2E is very dusty and abrasive. Teams may use honeycomb structures as long as they are strong enough to be safe and the edges sealed to prevent dust intrusion. Teams may not use GPS, rubber pneumatic tires; air/foam filled tires; open or closed cell foam, ultrasonic proximity sensors; or hydraulics because NASA does not anticipate the use of these on an off-world mission.

9.2 CONSTRUCTION INFORMATION

9.2.1 Team members shall "Suit-Up" and don their Personal Protective Equipment (PPE) to place their robot into the arena. The Arena Chief will make the final decision as to who places the robot into the arena, the number of team members allowed into the arena and any other operational process/procedure as required.

9.2.2 Teams at UCF will be required to perform two, 15-minute, construction attempts.

9.2.3 Surface features will consist of randomly placed craters and obstacles. The construction robot will be placed in the arena in a randomly selected starting position and direction. Assume there are positive and negative obstacles, assume you cannot drive over the obstacles. The obstacles may **not** be pushed to the side of the arena in the **obstacle zone**. The obstacles **may only** be pushed to the side of the arena in the **excavation zone**.

9.2.4 No physical access to the construction robot will be allowed during each competition attempt.

9.2.5 Arena team members are prohibited from pointing out obstacles/arena surface conditions to the Mission Control Center team members. In addition, telerobotic operators are only allowed to use data and video originating from the construction robot and the UCF video monitors.

9.2.6 Visual and auditory isolation of the telerobotic operators from the construction robot in the Mission Control Center is required during each competition attempt. Telerobotic operators will be able to observe the construction arena through overhead cameras in the construction arena via monitors that will be provided by

UCF in the Mission Control Center. These color monitors should be used for situational awareness only.

9.2.7 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 setup period, a handheld radio link will be provided between the Mission Control Center team members and team members setting up the construction robot in the construction arena to facilitate voice communications during the setup phase only. Violation of these rules will lead to disqualification.

9.3 CONSTRUCTION PROTOCOL

9.3.1 The robot will be inspected during the practice days and before each competition attempt. Teams will be permitted to repair or otherwise modify their construction robots while the RoboPits are open.

9.3.2 Teams are allowed to interact with an interface that allows different pieces of telemetry data to be viewed as long as there is no real time or other interaction to control or influence the robot. Teams must explain to the attending judge before each competition run how they are interacting with the telemetry system and the judge will observe to ensure compliance with competition rules.

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

9.3.4 Each team is allowed up to 10 minutes to place the construction robot in its designated starting position within the arena and 5 minutes to remove the robot after the attempt has ended and as directed by the Construction Judges

9.3.5 Teams at UCF will be required to perform two, 15-minute, construction attempts.

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

9.3.7 The robot is required to move from the starting area, across the obstacle area to the construction zone.

9.3.8 The robot may not acquire regolith simulant for the berm from inside the construction zone, all bulk regolith simulant for berm construction must be acquired from the excavation zone

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

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

9.3.11 At the start of each competition attempt, the robot may not occupy any location outside the defined starting position in the arena. The starting direction will be randomly selected by the Construction judges.

9.3.12 The robot must operate within the arena; it is not permitted to pass beyond the confines of the outside wall of the arena during each competition attempt.

9.3.13 The robot can separate itself intentionally, if desired, but all parts of the construction robot must be under the team's control at all times. The robot does not have to re-assemble prior to the end of the competition run.

9.3.14 The robot **shall not:**

- be anchored to the LHS-2E surface prior to the beginning of each competition attempt.
- ram the wall (may result in a safety disqualification for that attempt).
- use any aspect of the arena (wall, structure, column, etc.) in attempting any operations.
- use any process that causes the physical or chemical properties of the BP-1/LHS-2E to be changed or otherwise compromises the uniformity between attempts.

9.3.15 The robot will end operations immediately when the power-off command is sent, and/or as instructed by the Construction Judge.

10. NAVIGATION PROTOCOL

10.1 The team must declare the robot orientation by length and width to the inspection judge. An arrow on the reference point (the reference location and arrow pointing forward can be any point and direction of the team's choosing, except up) must mark the forward direction of the construction robot in the starting position configuration. The judges will use this reference point and arrow to orient the construction robot in the randomly selected direction and position (you can use a permanent-type marker) indicating the team's choice of forward direction on any location on the robot is acceptable as long as multiple arrows do not conflict. The arrow does not have to indicate the robot's preferred forward direction. The arrow is used only to orientate the robot prior to starting the robot run to face the robot arrow either north, east, south or west after spinning the direction wheel).

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

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

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

10.5 Target Beacons – beacons may be attached to any of the four corners of the berm box which will be marked on the regolith simulant surface. The beacons may be mounted on rods that are pushed into the regolith for anchoring.

10.6 The target/beacon may be a passive fiducial, or it may send a signal or light beam or use a laser-based detection system which has not been modified (optics or power). Only Class I or Class II laser or low powered lasers (< 5mW) are allowed. Supporting documentation from the laser instrumentation vendor must be provided to the inspection judges for "eye-safe" lasers.

10.7 Inertial measurement units (IMU) are allowed on the construction robot. Teams have to explain to the judges how the compass feature will be switched off or the compass data is subtracted to ensure the internal calculations do not make use of the compass (from any magnetic field surrounding the robot).

10.8 During each competition attempt, the construction robot is limited to autonomous and telerobotic operations only.

10.9 Telemetry to monitor the health of the construction robot is allowed during the autonomous period. Teams shall explain to the inspection/attending judge before each competition run how they are interacting with the telemetry system and the judge will observe to ensure compliance with all competition rules.

10.10 Teams shall not touch the controls during the autonomous period. Orientation data cannot be transmitted to the construction robot in the autonomous period.

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

10.12 The team must explain to the inspection judges how their autonomous systems work and prove that the autonomy sensors do not use the walls (there are no walls on off-world locations and teams shall operate as closely as possible on that scenario of operations). Integrity is expected of all team members and their faculty advisors.

10.13 Teams are allowed to interact with an interface that allows different pieces of telemetry data to be viewed as long as there is no real time or other interaction to control or influence the robot.

10.14 Teams are not permitted to update or alter the autonomy program to account / detect or upload information about obstacle locations. Failure to divulge the method of autonomy sensing shall result in disqualification from the competition.

11. ON-SITE COMPETITION AT UCF INFORMATION

11.1 PERSONAL PROTECTIVE EQUIPMENT (PPE) – this is not an all-inclusive list.

Remember to use good workshop, safety and engineering practices and principles. The RoboPit Chief and the Arena Chief are authorized to rule on any safety and health issues in their respective areas.

11.1.1 Protective eye wear must be worn in the RoboPits and the BotShop Volunteers and students who wear N-95 masks or other tight-fitting respirators shall be clean shaven. According to the National Institute for Occupational Safety and Health (NIOSH), that facial hair growing in or protruding into the area of the primary sealing surfaces of the respirator will prevent a good seal, and that workers should not enter a contaminated work area when conditions prevent a good seal of the respirator facepiece to the face. For this reason, only cleanshaven individuals wearing who wear N-95 masks or other tight-fitting respirators will be allowed entry into the UCF Arena during the competition. The requirement for personal protective equipment (PPE) is to protect the individual from the inherent dangers of crystalline silica (from the crushed lava basalt aggregate). There are very few options, but the best choice would be for the individual to purchase a hooded powered air purifying respirator (PAPR) – especially if they intend to stay in a career that requires the occasional use of PPE. This requirement exists for the safety of the participants. Whatever respirator is selected, it must be NIOSH-approved. [Statement from OSHA – Under OSHA, an employee cannot sign a waiver in order to be exempted from stated requirements. A release or waiver is not possible for employees. That being said when an employer is looking to accommodate a religious practice, they may have to explore respiratory protection alternatives like helmets or loose-fitting hoods].

11.1.2 Clothing - Allowed - Shirts/tops that cover upper torso. Pants or shorts. Completely enclosed shoes that cover the instep of the foot, preferably leather which can be wiped clean. Baseball caps and other headgear as long as they are kept far enough back on the head so that vision is not impaired and also do not interfere with protective eyewear.

11.1.3 Clothing: The following are not allowed - Hair must not impede vision or come in contact with the work. Hair must be kept away from the eyes. Long hair must be tied back. Hair longer than 6 inches from the nape of the neck must also be pinned up (use of hair nets or hats is acceptable). Flowing garments and neckwear such as ties and scarves that hang loose. Caps worn low over the eyes so as to impede vision. Cropped shirts, plunging necklines, spaghetti straps, or ripped shirts. Ripped jeans, shorts, capris, or skirts. Loose or flowing tops with wide/bell sleeves, outerwear such as coats or shawls. Sandals, open toe, open back, or open weave shoes, shoes with holes in the top or sides, no Birkenstocks, TEVA's, Choco's, Croc's, cloth shoes, or equivalents that will expose the skin to regolith or retain regolith.

11.1.4 Workshop, Safety & Engineering Practices - It is your responsibility to use the correct Personal Protective Equipment (PPE) for the situation. Remember to use hearing protection and eye protection (e.g., safety glasses, goggles or face shield) as needed. Use the right tool for the right job, wear gloves/gauntlets to de-energize robots and equipment as needed, bring jack-stands to support your

robot instead of folding chairs, wire strippers should be utilized instead of knives. etc. Bring your own LED lighting for your pit. Surgical or N95 masks are required inside for COVID precautions. Address any safety concerns to the RoboPit Chief immediately.

11.1.5 BotShop - Protective eye wear must be worn in the BotShop. Any work requiring protective equipment must be performed in the BotShop.

11.2 **Regolith Simulant** – SRT's Lunar Highlands Simulant (LHS-2E) is a mixture of Anorthosite and Basalt thought to be similar to lunar regolith at the South Pole and other highlands regions. It is alkaline and may cause skin and eye irritation. If you are allergic to talcum powder, it is a good indication that you may be allergic to the LHS-2E. Participants are required to don Personal Protective Equipment (PPE) before coming into contact with the LHS-2E. LHS-2E contains a small percentage of crystalline silica, which is a respiratory nuisance. Respiratory protection shall be used in accordance with the manufacturer's operating instructions and your school's respiratory protocols at a minimum. Without exception, the use of any respirator (N95 masks and/or tight-fitting negative pressure respirators, etc.) shall require a clean, shaven face. No facial hair shall be in contact with any part of the mask/respirator in order to maintain the seal.

11.3 Fire Exits / Eyewash Stations - Know where the fire exits, fire extinguishers and eyewash stations are located. Each team is responsible for bringing a First-Aid kit and respirator masks for use in the RoboPits for team members. Report any safety concerns to the RoboPits Chief.

11.4 Stop Work Order (SWO) - Lunabotics staff are authorized to issue a SWO to a team on any suspected safety issue. The team will immediately stop all activity. The Faculty Advisor must meet with the RoboPit Chief to resolve the issue. The SWO will remain in effect until the RoboPit Chief has issued a ruling on the issue. The RoboPit Chief decision is final.

11.5 Reminder - If your team uses any kind of military container, (ex. "ammo cans") please spray- paint or cover up the former military content signage so we can avoid any work stoppages due to extra security checks.

11.6 Controlled Substances - The consumption of alcoholic beverages or use of any controlled substances by a team member during the event is prohibited. Violation is grounds for disqualification of the team.

11.7 Weapons - *No weapons of any kind are permitted on the University of Central Florida property or inside Kennedy Space Center Visitor Complex*, including those belonging to off-duty law enforcement. Please leave items secured within your vehicle to expedite your entry into the visitor complex. Violation is grounds for disqualification of the team. For example, COTS wire strippers should be utilized instead of knives.

11.8 Unmanned Aerial Vehicles (UAV), Unmanned Aerial Systems - The use of Unmanned Aircraft Systems (Drones) is prohibited at the Kennedy Space Center Visitor Complex and the Astronauts Memorial Foundation Center for Space Education. The UAV/UAS will be confiscated and not returned. Violation is grounds for disqualification of the team.

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

11.10 Florida Weather - Stay hydrated, drink plenty of water. You and your off-world mining robots will be exposed to the Florida weather so be prepared for heat, humidity, wind and rain. You are responsible for protecting your robot from the elements while outdoors. Remember to have hats, sunglasses, insect repellent, sunscreen (SPF 50 or better) and a raincoat / poncho on hand for the competition. Florida is the Lightning Capital of the U.S., and the lightning phase conditions are as follows:

11.10.1 Phase I Lightning Condition - prepare to seek shelter.

11.10.2 Phase II Lightning Condition - seek shelter NOW in any building.

12. ROBOPIT PROTOCOLS

You are responsible for checking in with the RoboPits Chief upon arrival. The RoboPits Chief will explain the process for inspections, signing up for practice runs, and RoboPits protocols. The RoboPits Chief is your only point of contact to coordinate robot runs. When things get hectic, be professional. The RoboPits Chief will require two contact phone numbers, in case the team needs to be reached at any point during the competition and cannot be found. These numbers will not be shared with anyone and will be disposed of at the end of the competition. Each team will keep their team and equipment contained within their assigned pit and keep the walkways clear and unobstructed.

12.1 General Instructions

12.1.1 The RoboPits Chief will give the team leader the Comm/Inspection (C/I) card. The C/I card is to ensure that all teams have had their robot(s) checked out prior to entering the arena.

12.1.2 Communication (Comm) and Safety Inspection (C/I) locations will be identified.

12.1.3 Either inspection can be performed first, they are not scheduled, they are on a first-come, first-served basis.

12.1.4 Return the C/I card when you have passed both the Comm and Inspection checks and are ready for a practice run.

12.1.5 The RoboPits Chief will schedule the team for the next available practice (run) slot.

12.1.6 Check with the RoboPits Chief before heading to the arena for any schedule changes.

12.1.7 An escort will come to the RoboPit to guide the team to the Arena; do not leave without the escort.

13. ROBOTPIT GUIDE

13.2 Teams headed to the arena for competition runs have first priority on carts.

13.3 Following the inspection, the escort will take the team to the arena, where arena escorts will take over.

13.4 If the team is not ready or cannot be located, the competition run time will be given to another team that is ready.

13.5 All pits have power strips provided. Do not daisy chain power strips. Teams are encouraged to bring their own LED lighting.

13.6 It is recommended that the team be ready with the robot on a cart, 60 minutes prior to the scheduled competition start time, to ensure a smooth flow.

13.7 Transportation of the robots from the robopit to the arena will be provided. Use carts to transport robots only. Carts are NOT for use in your pit. Carts are not platforms for working on the robots.

13.8 Vacuums are provided. They are for shared use by all teams as needed. Return vacuums to the designated area. Notify the RoboPits Chief about vacuums that need to be cleaned.

13.9 On competition days, teams will be brought to inspection 60 minutes before the scheduled competition run start time.

13.10 Clean-up and Check-out - each team will leave their RoboPit as they found it. Teams are required to clean their pit and the area around it. Teams will request a RoboPit inspection from the RoboPit Chief.

13.11 Keep the RoboPit and the surrounding area neat and generally clean; use the provided vacuums as necessary. You are encouraged to bring floor coverings/mats to facilitate this cleaning.

13.12 Waste Accumulation and Disposal Protocol

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

Waste Accumulation and Disposal Protocol	
a. Batteries (Alkaline, Lithium, Ni-Cd)	j. Spray Paint
b. Oily wipes/IPA solvent wipes	k. Spray Foam
c. Solder waste	l. Spray Adhesives
d. Acetone wipes	m. WD40
e. PCV cement – brushes, wipes, and cans	n. PB Blaster
f. PVC primer – brushes, wipes, cans	o. Silicone Spray
g. Super Glue (cyanoacrylates)	p. Oil Cans
h. Epoxy Tubes	q. 3 in 1 oil
i. Aerosol Cans	r. any as required by regulations

For more information see:
https://www.epa.gov https://floridadep.gov

14. QUALIFICATION CHALLENGE WEEK AT UCF INFORMATION

Please check slack channel announcements for the qualification week guide!

APPENDIX A. GLOSSARY OF TERMS

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

2. **Astronaut Memorial Foundation's Center for Space Education (CSE):** Located adjacent to the northwest end of the Kennedy Space Center Visitor Complex (KSCVC), at the Eastern terminus of Florida S.R. 405 in building M6-306.

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

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

5. **Lunar Highlands Simulant 2mm Engineering Grade (LHS-2E): The Regolith Simulant used within the Exolith Lab Regolith Bin is Space Resource Technologies LHS-2E. A spec sheet for the simulant can be found here:** (LHS-2E) Engineering Grade Lunar Highlands Simulant – Space Resource Technologies

6. **Competition attempt:** The operation of a team's mining robot intended to meet all the requirements for winning the mining category by performing the functional task. The duration of each competition attempt is 15 minutes.
7. **Functional task:** The excavation of regolith simulant and deposition into berm structure.

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

9. **Lunar regolith density:** The density of regolith at the Apollo 15 landing site averages approximately 1.35 g/cm^3 for the top 30 cm, and it is approximately 1.85g/cm^3 at a depth of 60 cm. The regolith also includes breccia and rock fragments from the local bedrock. About half the weight of lunar soil is less than 60 to 80 microns in size.

10. **Construction arena:** Located within the Exolith Lab at the University of Central Florida

11. **Regolith Construction robot:** An autonomous or tele-operated robotic excavator including mechanical and electrical equipment, batteries, gases, fluids, and consumables delivered by a team to compete in the competition.

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

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

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

15. **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.

APPENDIX B. FROM GOOGLE SCHOLAR

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

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

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

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

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

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

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

TOWARDS IN-SITU MANUFACTURE OF MAGNETIC DEVICES FROM RARE EARTH MATERIALS MINED FROM ASTEROIDS
https://robotics.estec.esa.int/i-SAIRAS/isairas2018/Papers/Session%2010c/1_iSAIRAS_Ellery_2018_final-11-40

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

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

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

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

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

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

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

Affordable, Rapid Bootstrapping of the Space Industry and Solar System Civilization https://arxiv.org/abs/1612.03238

Additive Construction with Mobile Emplacement (ACME) https://www.researchgate.net/profile/Rodrigo-Romo-2/publication/322567924_Additive_Construction_with_Mobile_Emplacement_ACME/links/5a5ffe7faca2727352458863/Additive-Construction-with-Mobile-Emplacement-ACME.pdf

A Review of Extra-Terrestrial Mining Concepts https://ntrs.nasa.gov/citations/20120008777

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