Australian Rover Challenge 2022

Rules and Requirements

Australian Rover Challenge Vision

- Facilitate the growth of multidisciplinary student teams within Australia.
- Provide a platform for national collaboration towards technological innovation and development within the space industry.
- Pioneer full scale planetary simulation missions to validate new technologies towards resource utilisation on the Moon and Mars.
- Promote collaborative learning and friendly competition for new and growing Australian student teams.

Changelog

Several modifications have been made to various sections of the rules, too many to highlight in a changelog. It is recommended to compare this document with V2 using a tool of your choice. Please get in touch with the organising team on the ARC website if you no longer have access to V2.

1. Challenge Rules

1.1. "Team" refers to the individuals tasked with operating a Rover entry. A University is not limited in the amount of Teams that they may enter, and Teams from a single University do not have to contain unique Team members.

1.2. The Australian Rover Challenge (ARC) will be referred to as the *Challenge,* which is made up of the four *Tasks* set out in Sections 8-11. The tasks are made up of various point scoring *Activities.*

1.3. The individuals making up a Team shall be students of any study level. Guidance and assistance from university staff should be drawn upon, however direct, dedicated involvement from university staff is prohibited.

1.3.1. University staff in this respect refers to any university employee who is not actively studying to attain a higher level of education than they already hold. Students who hold casual or part time positions such as, but not limited to, demonstrating, tutoring or assisting research, are excluded from the definition of University staff as it applies in Rule 1.3.

1.3.2. There is a one year grace period to continue competing at the ARC after graduating. This is to assist with the handover of leadership between years and ensure that students who have made an impact on a Rover and Team are able to attend the Challenge.

1.3.3. It is highly recommended to have unique Team members with distinct roles and responsibilities at the Challenge to avoid confusion between operational requirements and procedures for each Rover, should a University submit multiple entries.

1.4. Cross-University hints, tips, tricks, advice and guidance within the spirit of the challenge is permitted and encouraged, however *collaboration* should be minimal.

1.5. Teams must complete a Preliminary Design Review, System Acceptance Review and Design Presentation throughout the Challenge, however Teams are not required to take part in each *Task* during the Challenge.

1.6. Teams are encouraged to review examples of terrain and obstacles in online media of previous iterations of Challenge. This information should be taken as an indication of how previous years have operated, and while changes are made to the Rules and Challenge from year to year, the *essence* of the Challenge remains similar.

1.7. The Tasks, briefings and events during the Challenge will occur at the University of Adelaide (North Terrace campus) in South Australia.

2. Key Dates

2.1. 29 Jan 2022 : Distributed Field Test

2.2. 11 Feb 2022 : SAR Due

2.3. 11 Feb 2022 : Design Presentation guidelines released

2.4. 04 Mar 2022 : Cost Report guidelines released

2.5. 21 Mar 2022 : Cost Report Due

2.6. 25-27 Mar 2022 : Australian Rover Challenge competition dates

3. Rover Rules

3.1. The Rover shall be a stand-alone, off-the-grid, mobile platform. Tethered power and communications are not allowed. A single connected platform must leave the designated start gate.

3.2. The essence of the Rover system shall be the same for all of the Tasks that a Team participates in. Different payloads and sensing systems may be present on the Rover in compliance with Rule 3.4, however, the platform of the Rover must be the same from task to task.

3.2.1. The “platform” of the Rover refers to the systems which make up the core of the Rover and cannot *easily* be changed or adjusted. This includes, but is not limited to, the chassis, suspension, core computing, power systems, and drive systems.

3.2.2. The “platform” of the Rover must not consist of a commercial-off-the-shelf unit.

3.3. Rovers shall be weighed by the judges during the set-up time of each Task. The Rover must be able to fit on the lander at the beginning of the first Task (Post-Landing Task) which constitutes a 1.6 x 1.6m square platform.

3.3.1. Rovers may articulate/fold/bend to fit within the lander, but may not be disassembled to do so. This includes wheels, antennas, and any other system protruding from the Rover.

3.3.2. There is no vertical height limit, and the Rover may be placed in any orientation.

3.3.3. Once a Rover is positioned on the lander in a configuration which meets the size requirements, interference from Team members is not permitted. That is, if the Rover articulates/folds/bends to fit within the lander, the Rover must be able to manoeuvre into a position to start the task by itself.

3.3.4. The same Rover footprint requirement will be used for all Tasks.

3.3.5. If a Team does not elect to compete in the first Task, they will be subject to the same size limitations for the Tasks that they do compete in.

3.3.6. Failure to fit within the specified dimensions will result in a 40% penalty for each Task with which the Rover is non-compliant.

3.4. The maximum allowable mass of the Rover when deployed for any competition Task is 50kg. The total mass of all fielded Rover parts for all events is 70kg.

3.4.1. For example, a modular Rover may have a robotic arm and a sensor that are never on the Rover at the same time. The combinations of Rover plus arm and Rover plus sensor must each be under 50kg. The total Rover plus arm plus sensor must be less than 70kg. The weight limits do not include any spares or tools used to prepare or maintain the Rover.

3.4.2. For each Task in which the Rover is overweight, Teams will be subject to a penalty of 5% per kilogram over 50kg. This penalty will be applied to the score that the Team obtains during the Task. For example, a 52kg Rover scoring 80 points will be awarded 72 points after the penalty is applied.

3.5. The total cost of the Rover (in its final form) and Base Station systems (that is everything that is required to operate the Rover) must be reported to the Challenge Judges no later than 21 March 2022, in the Cost Report.

3.5.1. Reportable costs do not include any Team labour, Team software (unless it is required to run the Base Station systems), research and development, plant, machinery and tools.

3.5.2. The reportable cost is that which any member of the public could acquire the components and parts that make up the whole Rover system (i.e. not including discounts of any type and including delivery or import fees).

3.5.2.1. The reportable cost of components manufactured by the Team includes the raw material and fees associated with acquiring the material (sales tax, import fees, shipping and handling).

3.5.2.2. The reportable cost of components manufactured by Team sponsors is the cost that the manufacturer would charge to a full-fee paying member of the public or industry. This is the reportable cost and is independent of any discounts or sponsorship (monetary or in-kind) provided to the Team.

3.5.3. Teams can expect in future iterations of the Challenge that incentives or points will be available for minimising the cost of the Rover and Base Station systems.

3.5.4. More information regarding the Cost Report and reportable costs will be available by 4 March 2022.

3.6. Rovers shall utilise power and propulsion systems that are applicable to operations on the Moon. Air-breathing systems are not permitted. No power, propulsion or auxiliary system may ingest ambient air for the purpose of combustion, other chemical reaction that yields energy or to operate any other process requiring the ambient air. There are no other requirements for which a Rover may adhere to Lunar conditions, however additional design features which adhere to operation on the Lunar surface may be looked upon favourably by the judges in the Design Presentation.

3.6.1. Rovers may carry onboard reservoirs of material to support pneumatic, hydraulic or other systems requiring such materials. Teams should take care to minimise outgassing and other loss of material. Teams should be wary of the hazards that pressure vessels present, and should take reasonable steps to minimise associated risk.

3.7. All Rovers shall have at least one “E-STOP switch” that consists of a red latching button with a yellow surround, that is readily visible and accessible on the exterior of the Rover. This is an example of an E-STOP. This switch shall immediately stop the Rover’s movement and cease all power draw from batteries in the event of an emergency such as a battery fire. All Rovers shall have a clear external indication of powered on/active status. Adherence to these two conditions are mandatory and failure to comply will forfeit a rover’s ability to compete in the Challenge.

3.7.1. Teams maintain responsibility for the safety of their Rover, as it pertains to other Challenge participants and the general public, at all times.

3.8. Communications

3.8.1. It is recommended that at least one member from each Team obtains an amateur radio licence.

3.8.2. Teams are responsible for ensuring that they comply with ACMA regulations for the frequency band in which they are operating.

3.8.3. Teams should ensure that their communications equipment can automatically or manually switch between frequency bands, should there be any interference from an uninformed third party.

3.8.4. The competition takes place at The University of Adelaide, which is a high RF (particularly WiFi) environment. Teams should consider this when designing their communications systems, and take steps to avoid foreseeable complications.

3.8.5. Based on information collected during the Preliminary Design Report, the organising committee will take further steps to ensure that interference during the Challenge tasks is minimised.

3.9. Base Station Antennas

3.9.1. Base Station antennas may be positioned during the set-up period and may only be repositioned by a Team member adhering to Rule 7.7.2.

3.9.2. Base Station antennas may be no greater than 3m tall.

3.9.3. Teams are required to supply their own cable at least 10m in length to reach from the Base Station to their antenna.

3.9.4. Antennas will be placed in close proximity to the Challenge Arena, in a small area designated by the judges, which means that a wide beam width is required to ensure reliable communication with the rover anywhere on the Challenge Arena. A minimum beam width of 90 degrees is recommended, unless active tracking technologies are used in combination with a more directional antenna.

3.9.5. Metal crowd barriers and large metal seating may line the Challenge Arena and surrounds, which can interfere with, or block, some wavelengths.

3.9.6. Teams are able to use any number of antennas, for example for different bands, as long as they are all positioned within the small antenna area adjacent to the Challenge Arena.

3.10. The Challenge Arena can see extreme weather such as hot and dry or cold and wet. Although rain is uncommon, Rovers should be able to operate in reasonably wet conditions - such as in a light shower. The judges will place a Task on intermission, should precipitation be great enough that Rovers are at risk of excessive water damage.

4. Scoring and Prizes

4.1. The scoring and prizes will be awarded by the judging panel for each Task. The judging panels will be made up of professionals from academia and industry, and will be confirmed closer to the Challenge.

4.2. Scores will be awarded for the Preliminary Design Review (as outlined in section 5), the System Acceptance Review (as outlined in section 6), the Design Presentation (as outlined in section 12) and each Task (as outlined in sections 8-11).

4.3. Prizes will be awarded to the Team with the highest score in each Task.

4.4. A prize will be awarded to the Team with the best documentation; the highest cumulative score for the Preliminary Design Review and System Acceptance Review.

4.5. A prize will be awarded to the Team with the highest score in the Design Presentation.

4.6. An overall Challenge prize will be awarded based on the sum of all scoring activities.

4.6.1. The overall challenge score will be out of 450 comprising; 4 x 100 Task points + 15 Preliminary Design Review points + 25 System Acceptance Review points + 10 Design Presentation points.

5. Preliminary Design Review

5.1. On 24 September 2021 Teams will be required to submit a Preliminary Design Review outlining core Rover systems, their readiness, and work expected to be completed before the Challenge.

5.2. Core Rover systems which will have to be reported upon include, but are not limited to:

5.2.1. Power systems, power delivery, and power safety

5.2.2. Drivetrain

5.2.3. Chassis construction and materials

5.2.4. Perception systems

5.2.5. Base station design and control

5.2.6. Rover communications

5.2.7. Drive control systems (software based)

5.2.8. Additional hardware and software that is specific to each task the Team intends to compete in.

5.3. Teams will also be required to supply a timeline, highlighting consequential tasks, and contingency plans for delayed completion of said tasks.

5.4. Teams are required to notify the organising committee of the tasks that their Rover plans to contest.

5.5. More detailed information and the Preliminary Design Review will be provided by 13 August 2021.

6. System Acceptance Review and Distributed Field Test

6.1. On 11 February 2022 Teams will be required to submit a System Acceptance Review (SAR) outlining the design of their systems, and approach to tasks they wish to compete in.

6.2. A remote Distributed Field Test (DFT) will be held on 29 January 2022. At a minimum, it is expected that a Rover will be able to be tele-operated to drive forward and turn on a simple simulated course environment (i.e, beach or sandy environment). This field testing will be held simultaneously in each Team's home location. The course and simple task will be further defined with the SAR. The purpose of the DFT is to provide Teams a developmental milestone to work toward, and to demonstrate to judges the validity of their SAR submission and readiness of their Rover.

6.3. More detailed information about the Distributed Field Test and System Acceptance Review will be provided by 24 November 2021.

6.4. Teams are required to demonstrate that their systems meet the minimum requirements to compete in the Challenge as outlined in this document which will be highlighted in the SAR requirements document. Failure to meet the minimum requirements may result in disqualification.

7. Challenge Task Logistics

7.1. The Challenge Arena is expected to be no smaller than 10 x 15m and consist of dry, fine-grained sand. Obstacles which Rovers may encounter include the Supply Caches which range in height and have footprints varying from 1 x 1m to 3 x 3m. Rocks may vary in size from passable 20cm objects to 1m rocks which may be necessary to avoid, depending on the design of a Rover. Ridges and craters may also be present which may present a challenge for Rovers to pass, or may be impassable. All challenge objectives and targets will be located such that traversal of large terrain features and obstacles can be avoided. Small objects (such as 20cm rocks or drops, or embankments of 30 degree slope and 0.5m height) may be necessary to traverse to navigate to all task activities during the allocated time period.

7.2. Teams will be given a field briefing at least 10 minutes before the start of their set-up time for each Task.

7.3. After the briefing, Teams will have at least 10 minutes before the beginning of each Task to set up their Base Station. The Base Station will include at least two 6-foot tables, four chairs and power sockets.

7.4. During set-up time:

7.4.1. Members from the Team may move freely between the Base Station and Challenge Arena, to ensure their Rover is working as planned.

7.4.2. The Base Station may communicate to other Team members in the field using hand-held radios provided by the judges, but Teams are encouraged to bring their own.

7.4.3. The Rover may not be operated in the Challenge Arena. An area adjacent to the Challenge Arena will be available to Teams to operate and test their Rover to ensure it is operating as planned prior to the beginning of the Task.

7.5. Once the set-up is complete, the Team will notify the judges, and the judges will instruct the Team to move the Rover to the start position for the Task. Once all team members are clear of the Challenge Arena, the Task will begin.
    7.5.1. A Team may start a Task before their set-up time elapses. Teams will not be granted additional time to complete the Task in this case.
    7.5.2. Teams may take longer than the allotted set-up time to ensure their Rover is working as planned, consuming their Task time. The Task timer will begin at the conclusion of the expected set-up time in this case.
7.6. Throughout the Challenge, Teams will be required to carry their Rover up to 100m. If Teams are unable to demonstrate that they are able to perform a safe 2-person carry of their Rover with minimal risk of injury (to those carrying and the general public), they will be required to make use of transportation equipment provided by the Challenge organisers (trolleys or otherwise) to move their Rover. This may result in lost time at critical moments of the Challenge.
7.7. Once a team has started a Task, Team members inside the Base Station are not permitted to communicate with Team members outside the Base Station in any way.
    7.7.1. Team members not inside the Base Station at the declaration of the start of the Task, will never be permitted to enter the Base Station during that Task.
    7.7.2. Team members inside the Base Station may leave at any time, however they will not be permitted to re-enter.
    7.7.3. Teams can expect a limit to the number of Team members allowable in the Base Station at the start of a Task, due to COVID density requirements. Teams should be prepared to operate, in the worst case, with four Base Station members. Base Station members may also have to wear masks while in the Base Station.
7.8. An intervention may be called by the Base Station at any time by clearly indicating this intent to the judges.
    7.8.1. Teams will receive a cumulative 10% deduction in points earned from the Task for each intervention called.
        7.8.1.1. For example, if a Team who scores 60 points before penalties are applied uses two interventions during the Task, their Task score will be 48 points as 20% is deducted due to the interventions.
    7.8.2. During an intervention, the Base Station may communicate to other Team members in the field using hand-held radios provided by the judges.
    7.8.3. Team members in the field must not relay any information describing any part of the Challenge Arena, and doing so will result in immediate termination of the Task.
    7.8.4. During an intervention, Base Station members are able to leave in accordance with Rule 7.7.2.
7.9. Teams will have at least 5 minutes at the conclusion of the Task to vacate the Base Station for the next Team.
7.10. Teams will be required to vacate the Challenge Arena as soon as the Task has finished.
7.11. Teams do not need to return to the start gate, or collect any deployed items (radio repeaters, cameras, tools, etc.) before the end of time for any of the missions. However, they must be collected immediately after the end of the Task.

8. Post-Landing Task

8.1. All teams will compete in the Post-Landing Task on Friday 25 March 2022.

8.2. 100 points will be available for the Post-Landing Task.

8.3. Teams will have at least 30 minutes to complete this Task.

8.4. Your Rover has just landed on the surface of Cabeus crater in the south pole of the Moon. Your Team is required to execute a series of activities to work towards establishing an operational In-Situ Resource Utilization (ISRU) outpost in preparation for a human landing in the upcoming Artemis III mission.

8.5. This is a staged Task in which the Rovers shall be required to perform a systems check of the Lander and site evaluation using images collected from onboard cameras and other sensing instruments of the Team's choosing. Rovers will be expected to complete the following;

8.6. Systems Check

8.6.1. **20 points** are available for descending down egress ramp on the Lander (start gate, 1.6m wide with 20 degree decline) and circumnavigating the Lander, noting any damage that has occurred to the Lander during flight and descent.

8.7. **Site Evaluation**

8.7.1. **40 points** are available for navigating to the designated Supply Caches (Solar Array & Communication Tower) and relaying the Status Readout message to judges. Obstacles of a range of difficulties may be encountered (i.e. rocks, bricks, berms, craters, etc.).

8.7.2. **10 points** are available for navigating to the Processing Plant, and using RFID to obtain the Status Readout message which contains instructions for carrying out Maintenance in the subsequent Activity. Points will be awarded for this Activity when the Base Station Team verbally relays these instructions to the judges.

8.7.2.1. If Teams fail to retrieve instructions via RFID, Base Station Judges can provide Maintenance instructions for the following Activity.

8.7.3. **20 points** are available for correctly performing Maintenance using a robotic arm, or otherwise, to interact with buttons, switches, dials, keyboard, plugs/sockets, joysticks or other graspable objects at the Processing Plant.

8.7.4. **10 points** are available for using RFID to alter the Status Readout message at the Processing Plant to confirm Maintenance has been performed, or has been attempted but is not complete. Points for this Activity will be awarded by the Field Judge who will verify the RFID Status Readout has been modified correctly.

8.7.4.1. For Example, if a Team attempts Maintenance but fails to complete all or some of the tasks, in order to score the 10 points they must alter the Status Readout message, for example, to "Task A, B & C complete. Task D incomplete."

8.8. Further details regarding the intricacies of the Activities will only be made available to the Base Station at the start of, or during, the Post-Landing Task.

8.9. Details about the use of RFID in this Task are in **Appendix A.**

9. Lunar Resources Task

9.1. All teams will compete in the Lunar Resources Task on Sunday 27 March 2022.

9.2. 100 points will be available for the Lunar Resources Task.

9.3. Teams will have at least 30 minutes to complete the field portion of this Task.

9.4. Your Rover is expected to conduct in-situ resource **Identification, Excavation** and **Deposition** at designated unexplored sample sites, to support the aim of establishing an ISRU outpost within Cabeus Crater. As a Discovery Class mission, a specific scientific objective for your Rover is to demonstrate in-situ **Processing** on the lunar surface, at a location sampled by the LCROSS mission with known volatile contents.

9.5. The primary objective for this task is to **Identify** which of three unexplored sample sites may yield the greatest amount of frozen water (H_2O) contained within the regolith (extraterrestrial soil), **Excavate** regolith from that location, and then **Deposit** the excavated regolith at the *Processing Plant* identified in the Post-Landing Task.

9.6. A secondary objective for this task is to conduct in-situ resource **Processing** using onboard Rover systems to extract liquid water from frozen regolith that is excavated from a designated fourth site which is known to have a high water content. Teams must not deposit remnant regolith from the fourth site into the *Processing Plant Cache*. Regolith from this site is only for use as part of **Processing,** to extract liquid water.

9.7. Teams will be given a field briefing by judges and will be tasked with investigating multiple sites of interest within 50m of the start gate. Rovers will be expected to complete the following;

9.8. **Identification.**

9.8.1. **5 points** are available for leaving the start gate.

9.8.2. **15 points** are available for traversing to and imaging each of the three unexplored sample sites (5 points is awarded for each site) using on-board cameras and sensors. Rovers are expected to investigate all three sample sites to determine if frozen water is present in the samples, and if so, to what extent. Teams must show the judges in the Base Station that the Rover has traversed to, and imaged, each site to receive the points.

9.8.3. Sample sites will consist of containers of ‘Lunar regolith simulant’ mixed with a given proportion of volatiles (e.g H_2O) as outlined in **Appendix B**, which will be frozen and then buried beneath a thin overburden so that the uppermost edge of the container is level with the ground. Each sample site will be clearly flagged to indicate the location of the buried container.

9.8.4. Each sample site will aim to represent a unique environment relevant to where frozen H_2O would occur in/adjacent to Cabeus Crater.

9.8.5. Rovers may use cameras, passive sensors or any other chosen method to investigate the unexplored sample sites.

9.8.6. Teams may *sample* a small amount of regolith from each unexplored sample site to aid in their Identification.

9.9. **Excavation.**

9.9.1. Teams **must select one** of the three unexplored sample sites to excavate regolith from. Teams may use mechanical means or any other approach chosen by the Team to excavate regolith from the ground.

9.10. **Deposition.**

9.10.1. **30 points** are available for transporting and depositing excavated regolith into a designated metal hopper (30 x 30cm opening) at the Processing Plant identified in the Post-Landing Task. The opening of the metal hopper will be no more than 10cm off the ground. See **Appendix B** for detailed breakdown of point allocation and marking for this Activity.

9.11. **Processing.**

9.11.1. **20 points** are available for the *in-situ* Processing of regolith to extract liquid water. Teams may only collect and process regolith from a designated fourth sample container, which will be identified during the field briefing by judges.

9.11.2. Processing must be performed entirely on-board the Rover within the allocated Task time. See **Appendix B** for detailed breakdown of point allocation and marking for this Activity.

9.11.3. Processed water must be collected as a liquid in any container (dimension, material or otherwise) of the Team's choosing, however the container **must be removable** and must be handed to judges promptly at the end of the Task.

9.11.4. If Teams add any material (i.e. chemical solvents) to the regolith, the amount must be recorded and must be able to be weighed. For example, if a liquid reagent is added, the starting and finishing mass of this reagent on the rover must be weighed in its reservoir in order for judges to calculate the Team's score for this Task.

9.12. Based on the data collected by the Rover, Teams will prepare a **Lunar Resources Presentation** for the judges.

9.12.1. **30 points** are available for presenting the Team's observations and answers to questions related to the following topics;

9.12.1.1. Scientific knowledge of Space Mission Design, Space Resources and knowledge of the Moon, its surface processes and polar environment.

9.12.1.2. Description of what each sample site represents in the context of Lunar surface geology and their potential for frozen water to be present.

9.12.1.3. Detailed site descriptions, water abundances and justifications of site selection.

9.12.1.4. Discussions on the characterisation, excavation, deposition and processing methods, if used.

9.12.1.5. Meaning of data collected with respect to the *in-situ* resource potential of the samples and the field site being suitable for ISRU and exploration.

9.12.2. The presentation (max 10 minutes in duration) will be given inside the Base Station and will begin 10 minutes after the conclusion of the field Activities, allowing Teams to review data collected by the Rover and prepare slides.

9.12.3. Team members from the field, including those who intervened are allowed to participate in the presentation. The presentation and discussion with the judges is allowed even if the Team was unsuccessful in collecting data with their Rover.

10. Lunar Construction Task

10.1. All teams will compete in the Lunar Construction Task on Saturday 26 March 2022.

10.2. 100 points will be available for the Lunar Construction Task.

10.3. Teams will have at least 30 minutes to complete this Task.

10.4. Your Rover is now expected to deploy navigational beacons and interact with the lunar environment in order to support the aim of establishing an autonomous ISRU outpost within Cabeus Crater.

10.5. The use of GNSS (GPS, GLONASS, Galileo, Baidou, QZSS) or any other off-board positioning system is **not** allowed in the Lunar Construction Task.

10.6. Rovers will be expected to complete the following;

10.7. **Deploy Beacons**

10.7.1. **5 points** are available for leaving the start gate.

10.7.2. **10 points** are available for deploying each Beacon at least 1 metre away from the nearest placed Beacon, up to a maximum of **30 points**.

10.7.2.1. Points are awarded for each Beacon that remains standing (with a height of at least 30cm) at the end of the Lunar Construction Task (i.e not toppled over).

10.7.3. A list of 6 possible *Target Landmarks (see rule 11.18.4)* and the Autonomous Task start gate will be provided to the Base Station before the commencement of the Lunar Construction Task to aid in the Team's placement of Beacons. It is up to Teams to decide where to place Beacons that will best assist in the Rover's autonomous navigation to Target Landmarks in the subsequent Autonomous Task.

10.7.4. Teams must design and build their own beacons. See **Appendix C** for detailed breakdown of design and deployment requirements for the Beacons.

10.7.4.1. Up to **10 points** are available for minimising the mass of your Beacons, outlined in detail in **Appendix C.**

10.8. A rocket has just taken off from a nearby landing pad to deliver processed water to the Lunar Gateway, but its exhaust plume has toppled over a protective berm structure and scattered Lunar Bricks and debris onto a road that connects the Processing Plant supply cache to the Mining Site identified in the Lunar Resources Task. Your Rover must now clear the debris and reconstruct the Berm to re-create a safely navigable road. Rovers may use perception systems, robotic arms, bulldozing blades or any other means deemed appropriate by the Team to interact with the environment to complete the Task activities.

10.9. **Clear Debris**

10.9.1. **30 points** are available for removing debris from the marked area. Debris may include 3D printed bricks of varying size and 'rocks' no larger than 30 x 30 x 30cm and no more than 2kg.

10.10. **Construction using bricks**

10.10.1. **25 points** are available for the reconstruction of the Berm using 3D printed Lunar Bricks. Points will be awarded for the height and number of bricks used that remain standing at the end of the Lunar Construction Task (i.e not toppled over).

10.10.1.1. The minimum dimensions of the Bricks will be 5 x 5 x 5 cm (L x W x H) whilst the maximum dimensions will be 12 x 12 x 12 cm.

10.10.1.2. Other materials including, but not limited to, regolith or rocks from the Lunar surface may be used by the Team.

10.11. The Autonomous Task will begin promptly after the conclusion of the Lunar Construction Task, after a short interchange. In the context of the lunar surface, the interchange can be thought of as Rover maintenance, where the Rover may be checked and modified by the Field Team.

10.11.1. Teams will have between 5 and 15 minutes before the Autonomous Task begins after the end of the Lunar Construction Task.

10.11.2. This circumstance is similar to an intervention in that Rules 7.4.2 & 7.8.2 - 7.8.4 apply.

10.11.2.1. Anyone outside the Base Station at the start of the Lunar Construction Task will not be permitted to enter the Base Station until the end of the Autonomous Task.

10.11.2.2. Any physical modifications to the Rover can be made during the interchange, including changes to the battery, payloads, sensors, etc.

10.11.2.3. The only information that the Field Team can relay to the Base Station Team is the physical condition of the Rover.

10.11.3. In the event that Teams are unable to deploy any Beacons during the Lunar Construction Task, or are unhappy with their Beacon placement, the Base Station may elect to have their Beacons placed on the field by their Field Team during the interchange.

10.11.3.1. Under no circumstance may the Field Team advise the Base Station on the condition or placement of Beacons during the interchange. Beacon repositioning must be decided by the Base Station.

10.11.3.2. Repositioning of Beacons will result in a points ceiling applied for the Autonomous Task as mentioned in Rule 11.12.

10.11.3.3. The Base Station and Field Team will be able to communicate during the interchange as an exception to Rule 7.8.3, however they must comply with all of the interchange Rules outlined above.

10.11.4. Teams can choose to carry or drive their Rover to the start gate of the Autonomous Task during the interchange in preparation for the commencement of the Autonomous Task.

11. Autonomous Task

11.1. All teams will compete in the Autonomous Task on Saturday 26 March 2022.

11.2. 100 points will be available for the Autonomous Task.

11.3. Teams will have at least 30 minutes to complete this Task.

11.4. Your Rover must now demonstrate its ability for semi- or fully-autonomous traversal of the ISRU outpost, in preparation for Human explorers in the upcoming Artemis missions.

11.5. This is a staged mission in which initially an operator may be present in the control loop but all planning and estimation operations must be done by the Rover and/or Base Station computing without human intervention or input. This limits the operator to navigate the Rover blindly (i.e. without access to visual or other spatial information). The smart navigation strategy, sensor fusion and image data processing are the essence of this task.

11.6. The Rover and Base Station may collect data during the Lunar Construction Task regarding the local environment to assist in navigation during the Autonomous Task.

11.6.1. For example, a map created by the Rover in the Lunar Construction Task may be viewed at any time by the Base Station Team, and may be continually updated by the Rover as long as the direct output of a sensor (camera image, LiDAR point cloud, or similar) is not viewed, in line with Rule 11.10.

11.7. On-board data processing shall be used for Rover localisation based on natural terrain, features and landmarks in the Challenge Arena.

11.8. Use of GNSS (GPS, GLONASS, Galileo, Baidou, QZSS) or any other off-board positioning system is **not** allowed in the Autonomous Task. In addition, any sensors which rely on earth characteristics (such as magnetometers/compass etc.) are **not** permitted. The aim of the Task is to simulate the conditions on the Lunar surface.

11.9. Any other types of sensors (i.e. Camera, LiDAR, RADAR, IMU, IR, odometer, sonar, bluetooth, Wifi, etc.) can be used for on-board localisation.

11.10. The operator, whether in semi- or fully-autonomous mode, is not permitted to view the output of a sensor (i.e. LiDAR, Stereocamera, etc.) at any time while the Rover is in Autonomous mode.

11.11. The Rover may be tele-operated (i.e. semi-autonomously) but only with position and orientation estimates available to the operator. This data can be presented in any form.

11.11.1. Stage 2 of the Autonomous Task will only be available to fully-autonomously operated Rovers, and hence, Teams choosing to operate solely semi-autonomously, will not be able to receive full points for the Task.

11.11.2. Teams are able to complete Stage 1 semi-autonomously, and transition to fully-autonomous operation to complete Stage 2.

11.12. As in rule 10.11.3, if Teams elect to reposition Beacons, the maximum number of points available to them will decrease by 5 points for each repositioned Beacon.

11.12.1. If a Team repositions 6 Beacons, their maximum available points for the Autonomous Task will be 70. For example, if the Team scores 50 points before the penalty is applied, they will receive 50 points for the Task. If a Team scores 80 points before the penalty is applied, they will receive 70 points for the Task.

11.12.2. A repositioning may include placing additional Beacons on the Challenge Arena even if they were not deployed by the Rover.

11.12.3. If a Team does not compete in the Lunar Construction Task, they will be able to place their own Beacons on the Challenge Arena during the set-up time for the Autonomous Task, which will take the place of the interchange between the Lunar Construction and Autonomous Tasks. Teams who do not compete in the Lunar Construction Task will not be subject to the penalty described in Rule 11.10 for placing their own Beacons.

11.13. The Autonomous Task is made up of 2 Stages which are each made up of a number of Activities. Rovers will begin the Task at a start gate designated by the judges, which will be relayed to the Base Station Team at the beginning of the Lunar Construction Task.

11.13.1. The Rover will begin subsequent Activities from their position at the end of the preceding Activity, unless no points have been scored and the Rover is repositioned to the start gate in accordance with Rule 11.17.2.

11.14. Whilst at the starting position for each Activity, the Base Station is able to freely communicate with the Rover to arrange the safest path for the Rover to travel to the next Target Landmark.

11.14.1. Whilst at the starting position for each Activity, the Base Station may refer to data collected during the Lunar Construction Task as in Rule 11.6.

11.15. Teams are required to declare to the judges when the Rover will enter fully- or semi-autonomous operation, to begin searching for the Target Landmark for each Activity.

11.15.1. At any time during an Activity, the only data that may be transmitted from the Rover to the Base Station are its position ([x, y, z]) and orientation (Euler angles or quaternion). If Teams are utilising ROS, this is the equivalent of sending pose messages (ROS geometry_msgs/Pose) from the Rover to the Base Station.

11.15.2. During an Activity, the position and orientation of the Rover may be visualised with the assistance of data gathered during the Lunar Construction Task.

11.16. The Base Station are required to declare to the judges when the Rover has completed its search for the Target Landmark in each Activity.

11.16.1. The judges will then indicate to the Team the amount of points scored for the Activity. The Base Station Team will then be able to accept the points and begin the next Activity from their current position, or elect to re-attempt the Activity from the start gate of the Task as described in Rule 11.13.

11.17. The Base Station can choose to re-attempt an Activity at any time and direct the field Team to reposition the Rover to the start gate of the *Task*, *not* the starting position and orientation of that Activity.

11.17.1. If Teams re-attempt an Activity, the maximum available points for that Activity will then be reduced by 33% of the *available* points for the Activity.

11.17.1.1. For example, if the Rover, on its third attempt at the Activity (after two re-attempts), positions itself where it would have received all of the points available for the Activity, only 33% of the available points for that Activity will be awarded.

11.17.2. If a Rover is unable to complete an Activity on its third attempt, and the Team would like to progress to the next Activity the Rover may attempt the next Activity from its current position, or be relocated to the start gate of the Task. The Team will receive no points for the Activity in this case.

11.17.3. Teams do not have to attempt an Activity three times before progressing to the next Activity. The Base Station may choose to abandon an Activity at any time and opt to begin the next Activity from their current position or from the start gate of the Task.

11.18. Terminology

11.18.1. The *Supply Caches* are large physical and artificial structures.

11.18.2. *Terrain Features* are made from the shape of the regolith, for example, craters, berms, and mounds.

11.18.3. *Artificial Obstacles* are large rocks or boulders, the wall built by the Rover in Lunar Construction, and the fencing surrounding the Challenge Arena.

11.18.4. *Target Landmarks* can be *Supply Caches* **or** *Terrain Features* and make up the possible destinations for Autonomous Task activities. A Target Landmark out of the possible list provided during Rule 10.7.3 will be relayed to the Base Station Team verbally at the start of each Activity.

11.19. Teams will incur a penalty for each collision with an Artificial Obstacle or Supply Cache.

11.19.1. Team members on-field may press the E-STOP at any time, such as preventing a Rover from colliding with a Supply Cache or Artificial Obstacle. It is therefore recommended that Teams can recover quickly, following an E-STOP.

11.19.2. After the E-STOP is pressed, the Rover will be moved back to the start gate of the Task and the reposition will be treated as a re-attempt as in Rule 11.17.

11.19.3. If a Rover does collide with a Supply Cache or Artificial Obstacle, the Rover will be repositioned to the start gate and treated as a re-attempt under Rule 11.17, however the maximum available points for the activity will then be reduced by 50% of the *total* points for the activity they are currently completing.

11.19.3.1. For example, if on the *second* attempt at an Activity, a Rover collides with a Supply Cache, the Rover will be repositioned to the start gate of the Task and have the option to re-attempt the Activity to score a maximum of 16.67% of the available points (33.33% reduction as it was originally their second attempt **and** 50% reduction of total Activity points for the collision) or abandon the activity and attempt the next Activity.

11.20. Stage 1

11.20.1. Teams will be required to fully- or semi-autonomously navigate to Target Landmarks.

11.20.2. Stage 1 will have 4 Activities worth 10 points each for a total of **40 points**.

11.20.3. Full points will be awarded for each Activity if the minimum distance between the Target Landmark and the Rover is less than 1.5m.

11.20.4. No fraction of points available for an Activity will be awarded (before a penalty is applied).

11.21. Stage 2

11.21.1. Teams will be required to fully-autonomously navigate to Target Landmarks.

11.21.2. Stage 2 will have 3 Activities worth 20 points each for a total of **60 points**.
11.21.3. Full points will be awarded for each Activity if the minimum distance between the Target Landmark and the Rover is less than 1.0m.

12. Design Presentation

12.1. All teams are required to participate in a Design Presentation on Sunday 27 March 2022 to succinctly communicate why their Rover design should be chosen for a selected mission profile. Teams are expected to review the performance of the Rover for each of the Tasks it participated in, with a focus on addressing problems that were faced, how the Team handled them, and the result.
12.2. The purpose of the Design Presentation is to create an open dialogue between Teams and judges on their performance at the Challenge, and provide an invaluable opportunity for Teams to gain insights from external partners on the strengths and weaknesses of their Rover. It is also designed to give participating Teams a meaningful experience of an engineering review of their system.
12.3. Presentations will occur after all Tasks are completed.
12.4. Teams will be required to present on the information in their System Acceptance Review, performance in each of the Tasks, and answer questions from the judges.
12.5. A specialist panel including industry partners, scientists and engineers will judge the Presentations, provide feedback and guide the Q&A discussion.
12.6. Teams will be expected to first;
12.6.1. Discuss the overall approach and Rover design,
12.6.2. Explain their decision making when approaching Tasks,
12.6.3. Reflect on the performance for each Task to identify aspects of the Rover, operation or otherwise, that may be improved for the future, and;
12.6.4. Present information gained about the Lunar environment by their Rover in the field, over the course of the Tasks that they have completed.
12.7. Teams will be subject to a Q&A at the conclusion of their Presentation, and hence, Teams shall ensure that their Presentation panel has the required expertise to answer possible questions about the Rover system and approach to Tasks.
12.8. There are a maximum of 10 points awarded for the Design Presentation.
12.9. More information about the Presentation will be provided no later than the 11 February 2022.

Appendix A : Post-Landing Task

An RFID encoded Card (~85 x 54mm) will be attached to the exterior of the Processing Plant and have the following features:

- The Card will be at a height between 30 and 100cm from the surface of the Challenge arena.
- The exterior face with which the Card is mounted to will have no protrusions (such as buttons or dials) within 20cm of the Card.
- The Card will be placed on a face of the Processing Plant that does not have any obstructions near the surface of the Challenge arena such as the Processing Plant support legs or material conveyor belt.

The RFID Card will use 13.56MHz and the SPI communications protocol. The judges will use the RC522 to write to and read from the RFID Card using the MFRC522 library.

The RFID Card contains 64 blocks of 16 hexadecimal bytes. Block 0 contains manufacturer data, while every fourth Block (3, 7, 11, and so on) are sector trailers which contain access bits for read and write access to the remaining three Blocks in that sector. There are therefore 47 Blocks which can be altered on the RFID Card to encode a string of text as a message. The Status Readout message can be obtained by concatenating the data (string of text, stored as hexadecimal bytes) in each of the alterable Blocks, in ascending order (Blocks 1, 2, 4, and so on). The judges will read the card at the end of the task to determine if points are to be awarded to the Team for writing to the RFID Card.

Appendix B: Lunar Resources Task

Sample Preparation Guidelines

To ensure that each Team around Australia uses, and has access to, the same material to create the Lunar Resources samples, and to ensure repeatability when competing at the Australian Rover Challenge, the following materials will be used (due to low cost, availability and safety for Teams) ;

- Bunnings Bag of White Washed Sand
- Water
- Oven & Tray
- 3 x Plastic Containers with lid (At Least 100mm wide x 100mm long x 80mm tall
    - (e.g Decor Match Ups Basics Container Oblong Red 1L | Coles Online)
- Ziploc Bags

Methodology

(Modified from Atkinson 2019, Section 7.2.1)

1. Pour Sand to loosely fill each of the 3 containers to brim.
    a. This is the maximum volume of material each container requires.
2. Preheat oven to 120℃.
3. Pour and spread the Sand from one container evenly onto a baking tray.
4. Once the oven is heated and sample trays are ready, bake at 120℃ ± 5℃ for at least 4 hours.
    a. If possible, do all three trays at once.
5. Once dry, remove one tray and immediately close the oven door to prevent moisture addition.
6. Slowly pour the dry Sand into a large Ziploc bag, using a measured beaker or syringe add a known amount of water to the ziploc bag to make the overall weight (%) of the simulant to a known value, e.g 2.5, 5 wt% or 10 wt% water.
7. Seal the bag and then mix the water into the Sand, breaking up clumps and evenly distributing the water by hand.
8. The masses of Sand, water, and mixtures of the two should be recorded before and after to ensure accurate moisture content
9. Once mixing is complete, place the ziploc bags somewhere at room temperature and let them ‘cure’ overnight, allowing water to evenly distribute via capillary forces.
10. To verify the water content of the prepared simulants (in weight %), small samples can be removed and measured as per ASTM International - D2216-71.
11. Once cured, pour the wet simulant into an empty plastic container and freeze overnight.

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Point allocation for Identification, Excavation & Deposition

Points are awarded corresponding to a *base score* which is dependent on the total mass deposited to the metal hopper at the processing plant, and a *multiplier* based upon the sample site which the regolith was excavated from. A Team's score for Deposition will also depend upon the performance of other Teams.

- Your score for Depositing regolith will be calculated on the mass of regolith you deposit into the hopper from the unexplored sample site that your Rover excavated material from.
- If your Rover deposits the most amount of material to the processing plant, your base score will be the full amount of points available, e.g 30 / 30 pts.
- If the most amount of material deposited is 400g (deposited by a different rover), and your Rover is able to deposit 200g of material, your base score will be 15.
- Remnant or other material from the processing site may not be deposited to the hopper on the processing plant and Teams should take reasonable steps to avoid this.

$$Deposit\ Points\ (30\ Points\ Available)\ = 30\ * S_m * \frac{M_{Deposit,\ Your\ Team}}{M_{Deposit,\ Best\ Team}} \qquad \textit{Equation 1}$$

Where S_m is the Sample Site Multiplier (1, 0.5 or 0), $M_{Deposit,\ Your\ Team}$ is the mass (g) of regolith deposited in the **Hopper** by **your Team**, and $M_{Deposit,\ Best\ Team}$ is the mass (g) of regolith deposited in the **Hopper** by **any Team.**

- If your Rover deposits the most amount of material of all Rovers, and it is from the high quality site, your multiplier will be 1, and the total points for the deposit stage will be equal to your base score.
- If your Rover deposits 200g of material from the medium quality site, your multiplier will be 0.5, and your total points awarded for the deposit stage, using the example above, will be 7.5 / 30 (given that another Rover was able to deposit 400g of material from any site).
- If your Rover deposits material from the low quality site, your multiplier will be 0, and you will receive 0 points for deposition.

Point allocation for Processing

If a Team attempts to process regolith in-situ, immediately after the finish time of the on-field portion of the Lunar Resources Task the Field Team must give judges the **Liquid Container** containing the extracted liquid water. A Team's score for Processing will also depend upon the performance of other Teams.

The Processing score for the mass of water collected will be determined by the following formula:

$$Process\ Points\ (20\ Points\ available)\ =\ 20\ *\ \frac{M_{Water,\ Your\ Team}\ -\ M_{Particulates}}{M_{Excavated}\ *\frac{Water_{Site}}{100}}\ *\ \frac{M_{Water,\ Your\ Team}}{M_{Water,\ Best\ Team}}$$

Equation 2

- $M_{Water,\ Your\ Team}$ is the mass (g) of water collected from your **Liquid Container.** $M_{Water,\ Best\ Team}$ is the largest mass (g) of water collected by any Team.
    - $M_{water,\ Your\ Team}$ will be determined by pouring water from the **Liquid Container** into a conical flask with filter paper, on a tared, high accuracy scale (0.001g). The *Total Mass* will be measured, where the mass of the conical flask and filter paper (*Starting Mass*) will be known. The 'dirty' filter paper will be removed and weighed and $M_{particulates}$ will be calculated where $M_{particulates}$ = *Mass of dirty filter paper - Mass of clean filter paper.* Therefore, M_{water} = *Total Mass - Starting Mass -* $M_{particulates}$
- If $M_{Particulates} > M_{water}$ a Team's Process points will be 0. Any liquid contaminant/additive will be recorded according to Rule 9.10.4 and added to $M_{Particulates}$.
- $Water_{Site}$ is the water content (e.g 10%wt.) of the designated processing site and is constant for all Teams. This is used to determine how much water was available in the sample, to evaluate how much a Team extracted and how efficient Processing was.
- $M_{Excavated}$ is the total mass, including liquid water by mass, which was *excavated* from the designated sample site for Processing, which contains a known amount of Water . The samples will be weighed by the judges in advance of the task, and after the task to determine $M_{Excavated}$.

Example

Note: The Water contents of Site 1, 2 and 3 are placeholders. Do not expect these amounts to be realistic during the Challenge. In this example the known amount of Water at the designated sample site for Processing is 10%wt.

Team 1 (Total : 30 points)
Team 1 **Deposits** 100g of regolith from unexplored sample site 1 (contains 10 wt% water) to the Processing Plant. This is the most amount of regolith deposited out of all of the Teams in this example.

As they deposited the most regolith overall, their base deposition score is all available 30 points for **Deposition**. Their multiplier is 1 because they collected from the high water content site (site 1) and their **Deposition** score is 30 points.

They do not attempt **Processing.**
The team receives 0 points for **Processing.**

Team 2 (Total : 12 points)
Team 2 **Deposits** 80g of regolith from the unexplored sample site 2 (contains 5 wt% water) to the Processing Plant.

As they deposited 80g (compared to Team 1's 100g), their base deposition score is 80/100 of available 30 points (24 points) for **Deposition.** Their multiplier is 0.5 because they collected from the medium-quality water content site (site 2) and so their **Deposition** score is 12 points (24 x 0.5).

They do not attempt **Processing.**
Team 2 receives 0 points for **Processing**.

Team 3 (Total : 34 points)
Team 3 **Deposits** 80g of regolith from unexplored sample site 1 (contains 10 wt% water) to the Processing Plant.

As Team 3 deposited 80g from unexplored sample site 1 (compared to Team 1's 100g), their base deposition score (24 points) is 80/100 of available points for **Deposition.** Their multiplier is 1.0 because they collected from the high-quality water content site (Site 1) and so their **Deposition** score is 24 points (24 x 1.0).

Team 3 **Process** 10g of water with 5g of particulates from 100g of excavated regolith from the designated sample site with known water content. Team 3 and Team 4 collected the equal most amount of water during **Processing**.
Using Equation 2 Team 3 receives 10 points for **Processing.**

$$Process\ Points\ = 20 * \frac{10-5}{100*\frac{10}{100}} * \frac{10}{10} = 10\ points$$

Team 4 (Total : 47 points)
Team 4 **Deposists** 90g of regolith from the unexplored site 1 (contains 10 wt% water) to the Processing Plant.

As Team 4 deposited 90g from site 1 (compared to Team 1's 100g), their base deposition score is 90/100 of available points for **Deposition**. Their multiplier is 1.0 because they collected from the high-quality water content site (site 1) and so their **Deposition** score is 27 points (27 x 1.0).

Team 4 **Process** 10g of water with 0g of particulates from 100g of excavated regolith from the designated sample site with known water content.
Using Equation 2 Team 4 receives 20 points for **Processing.**

$$Process\ Points\ = 20\ * \frac{10-0}{100*\frac{10}{100}} * \frac{10}{10} = \ 20\ points$$

Team 5 (Total : 24.25 points)
Team 5 **Deposits** 95g of regolith from unexplored sample site 2 (contains 5 wt% water) to the Processing Plant.

As they deposited 95g (compared to Team 1's 100g), their base deposition score is 95/100 of available points for **Deposition**. Their multiplier is 0.5 because they collected from the medium-quality water content site (site 2) and so their **Deposition** score is 14.25 points (28.5 x 0.5).

Team 5 **Process** 5g of water with 0g of particulates from 50g of excavated regolith from the designated sample site with known water content.
Using Equation 2 Team 5 receives 10 points for **Processing.**

$$Process\ Points\ = 20\ * \frac{5-0}{50*\frac{10}{100}} * \frac{5}{10}\ = 10\ points$$

*In summary, these examples illustrate 1) the importance of **Identifying** the highest quality site, 2) the importance of **Excavating and Delivering** the most (mass) of material, and 3) the importance of being the most efficient in **Processing** material to extract water with the least amount of particulates.*

Appendix C: Lunar Construction Task

Teams must deploy beacons. Teams must design and build their own Beacons. Beacons must be stored in a Beacon Box on the Lander during the set up time of the Task. A maximum of 6 Beacons may be placed in the Beacon Box and deployed during the Task.

The Beacon Box will consist of a planform area of at least 30 x 120cm. The base of the box will be between 30 and 100cm off the Lunar surface. The Beacon Box will not have a lid and the front side will be open, meaning that Beacons are not restricted in height and can be accessed by the Rover from the front or the top. A stand is permitted to be placed in the Beacon Box to arrange the Beacons to the Team's liking, however the mass of this stand will be divided by the number of Beacons and contribute to the Beacon mass.

Beacons must not penetrate the Challenge Arena surface, nor purposefully make contact with any Supply Caches or Artificial Obstacles upon deployment.

The purpose of designing your own, lightweight Beacons is to demonstrate novel solutions to deployment mechanisms of sensors on the Lunar surface, and to also achieve this by minimising initial launch mass.

Beacon Design Requirements

- All Beacons must measure at least 30cm tall.
- Beacons must have an easily recognisable orientation, such as a marking or object at the "top", or base at the "bottom" which is clear to an observer. The Beacon must reasonably be able to be deployed upright. For example, Beacons may not be a 30cm stick with a coloured end designating the "top".
- Teams may place any type of marking or object on their Beacons at any height to assist with fully- or semi- autonomous navigation.
- No Beacon can have a cross sectional area, at any point along its height, greater than a 30 x 30cm square.
- Beacons may be active. They may be powered, engage in short range communication or any other local active tracking methods.
- 10 points are available for minimising the mass of Beacons as shown by the equation below.

$$Beacon\ Mass\ Score\ (10\ Points\ available)\ = 10\ - \frac{M_{Beacon}}{30}$$

- M_{Beacon} is the mass (g) of the Team's heaviest Beacon rounded to the nearest 10g. Teams cannot score negative points for the Beacon Mass Score. Teams must have at least two reasonably identical Beacons to obtain a Beacon Mass Score. Beacons may vary only slightly for purposes required to differentiate the Beacons during the Autonomous Task.