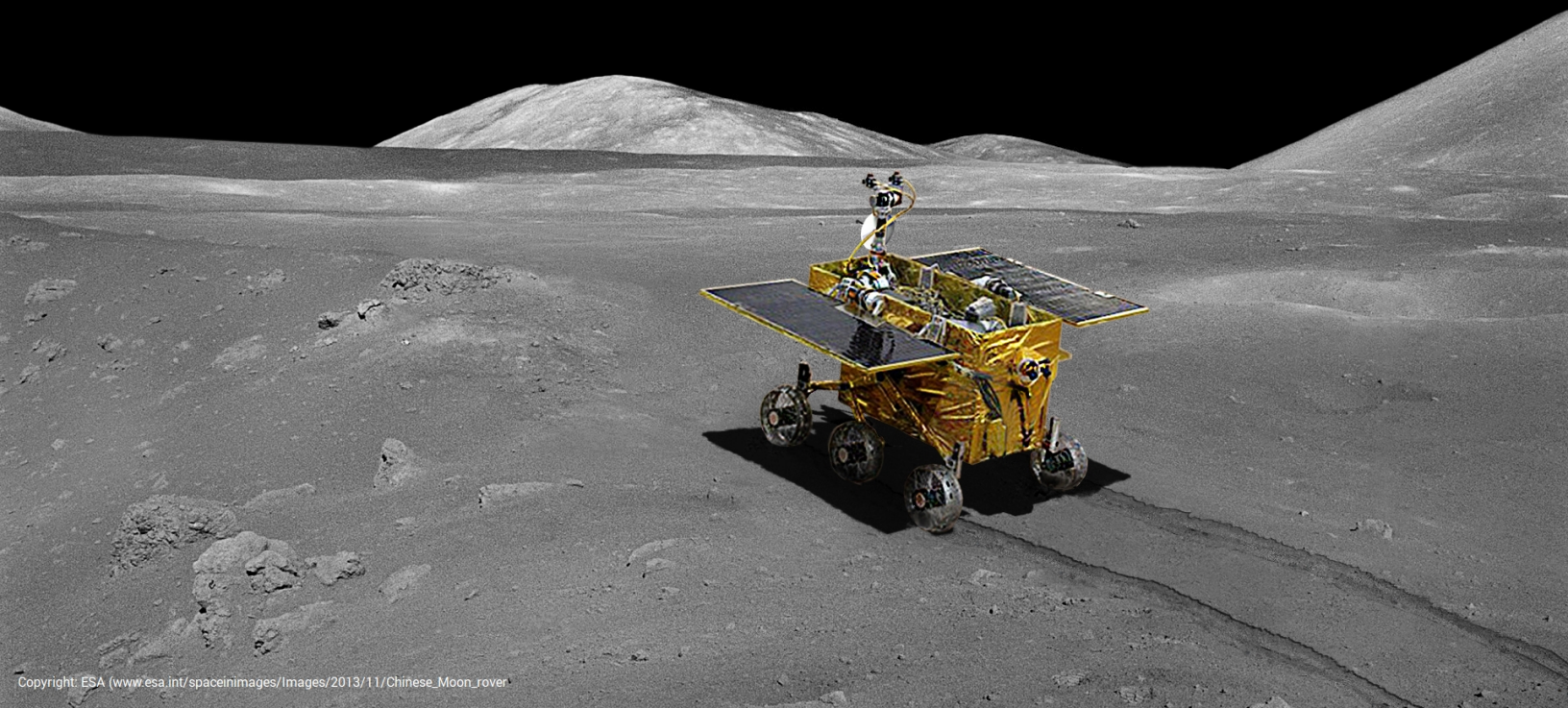
UKSEDS
LUNAR ROVER COMPETITION

Rules and Requirements

2016 - 2017



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1 Introduction

The UKSEDS Lunar Rover Competition challenges student teams to design, construct and operate a lunar rover, in order to perform a task that is representative of a real mission. The competition has been designed to be carried out by either an undergraduate group research project, or by a team from a UKSEDS branch.

The competition is held across the academic year, beginning in October 2016, and ending in July 2017. A schedule has been included in section 2.2.1.

1.1 Competition Objectives

1. Challenge students to perform a complex, systems engineering task of the development of a vehicle to a set of real **space missions requirements**;
2. Enable students to apply taught technical skills and learn new ones **relevant to a job** in the space industry in an applicable project environment;
3. Provide students with an opportunity to develop and practice other important and **marketable skills**, such as teamwork, leadership and project management;
4. Foster **wider interest in the activities of the space sector**, especially in space engineering and robotics.

1.2 This Document

This document is formatted in the style of an ESA (European Space Agency) ITT (Invitation to Tender). ESA publishes an ITT when they want to request for companies to bid for a contract. It is organised with a brief competition overview followed by a comprehensive statement of work - a description of the activities and deliverables during the competition.

This is followed by a series of Appendices, the key ones being the Competition Rules, the Technical Specification and the Deliverables Specification. These contain the bulk of the information a team needs to enter the competition and build a rover.

2 Competition Overview

This section has a brief description of all the major components of the competition, and includes references to additional material where necessary.

2.1 Mission Background and Context

The Moon has ever been an attractive target for human exploration. The US and Soviet Union started an intense exploration period during the 60's and 70's, culminating with the successful human missions of the Apollo Program. Other space groups, including JAXA (Japan Aerospace Exploration Agency), CNSA (China National Space Administration) and ESA have since visited the Moon. There have been 71 successful exploration missions to the moon, and 38 failures. Proposals for using the Moon as a space colony have been made since the dawn of the space age, but now the technology is finally catching up with imagination.

China, Russia and Europe have all made commitments to the Moon being the next destination for human exploration. One of the requirements for permanent human habitation is the supply of water. Water is both necessary for human consumption, but can also be used to provide oxygen and

Figure 1: ESA Moon Village [Credit: ESA]

hydrogen, for rocket propellant or life support. This makes the presence of water on the moon to be of prime importance to future colonisation plans, and future missions to find water are very likely.

2.2 Mission Scenario

In 2010 ESA carried out a design study on an ambitious robotic mission to the Lunar south pole. The mission intended to place a 750kg lander on the rim Shackleton Crater; a 21km wide, 4km deep impact crater near the geographical south pole of the Moon.

Due to its location, and the minimal seasonal tilt of the Moon, the base of the crater has not seen sunlight for millions of years and it is theorised that this allows deposits of ice and other volatiles to survive which were delivered by millions of years of comet impacts. Ice is seen as a critical resource for the establishment of a permanently manned Lunar base as it can be used to create drinking water, air and split into oxygen and hydrogen for use as a rocket fuel. However it would currently cost over $10,000/kg of water if sent from the Earth to the Moon via rocket and so being able to make use of natural deposits would be a significant cost saver.

As the lander was solar powered and was too heavy to give a locomotion system, it was designed to stay at the rim of the crater where sunlight is plentiful and the nights are short. The lander was to carry a small rover, deployed by a robotic arm, that had the primary task of driving down the crater slope to retrieve samples from the shadowy depths. It would then drive back up the slope to return to the lander where it would be grabbed by the robotic arm and its sample contents tipped into analysis instrumentation. The samples were then to be analysed to determine the amount of ice as well as assess its potential toxicity to Humans.

This mission was to be a precursor to the creation of a permanent manned Lunar base; an ambition which has been recently been revitalised by ESAfis moon village concept and the Google Lunar X-Prize. Therefore the need for miniature rovers which can get to the bottom of Shackleton has returned and this competition is intended to help students design the moon rovers of tomorrow.

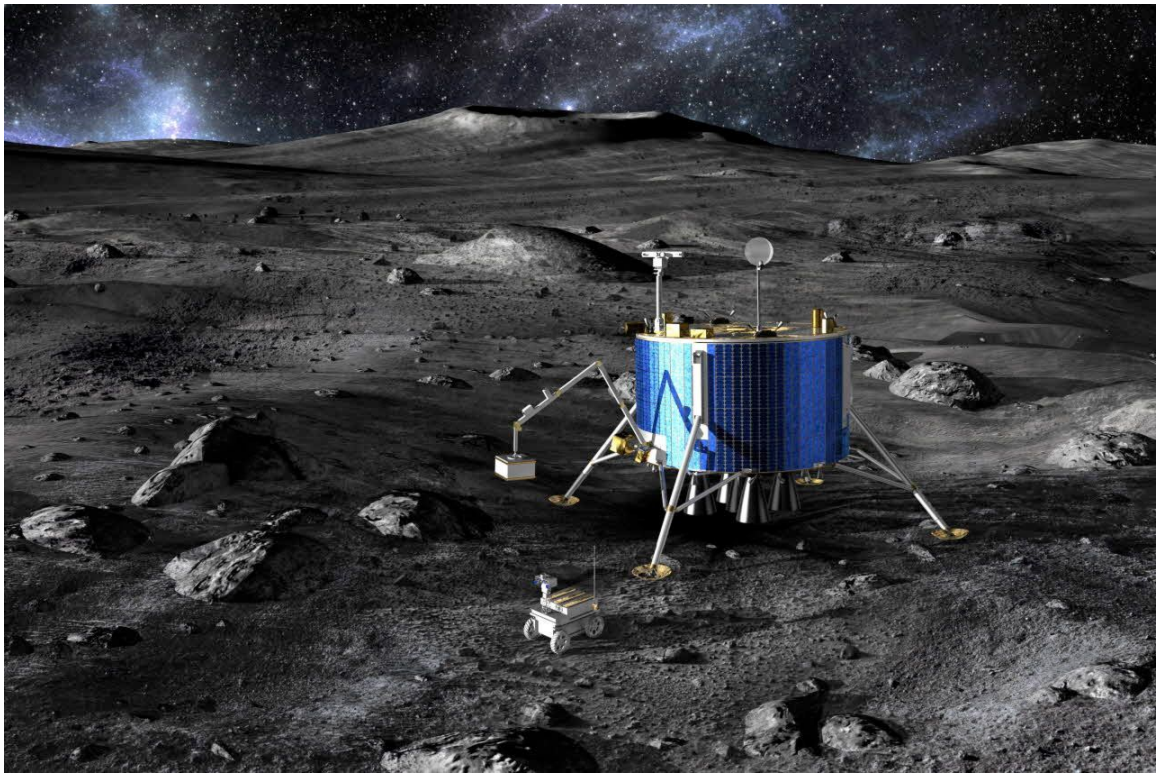

Figure 2: ESA Lunar Lander Mission with sample rover [Credit: ESA/DLR]

2.3 Mission Tasks

The challenge to the student team is design, build and operate a small rover on a mission modelled around lunar exploration. Lunar exploration has been of active interest for over 50 years, and there has been a renewed interest recently by both foreign nations like Russia and China, and within ESA as part of the Moon Village concept.

The primary mission objective for the competition is to navigate into the bottom of a crater, retrieve a soil sample, and return to the edge of the crater area. This consists of three components:

1. **Entering the crater:** The rover will need to move from the lip of the crater, down the slope to a designated point.
2. **Retrieving a soil sample:** A soil sample must be retrieved from the designated sample site within the crater.
3. **Returning to the lander:** The rover must then return itself with the soil sample to the starting point. The mission is complete when the rover returns to this point.

Further details on how these tasks are marked will be contained in the Rules and Scoring Criteria sections of the Appendix. The competition day itself consists of three components; an initial attempt to complete the objectives, a vibration test on a vibration table at RALSpace and a final attempt to complete the objectives.

2.4 Competition Schedule

The Lunar rover competition consists of several stages, which have been illustrated in fig. 3. A comprehensive overview of the tasks and deliverables are located in the Description of Work (section 3)

and in appendix E. Each deliverable must be handed in on time to the competition organisers for a team to progress to the next stage. Of particular importance are the PDR and CDR Reports.

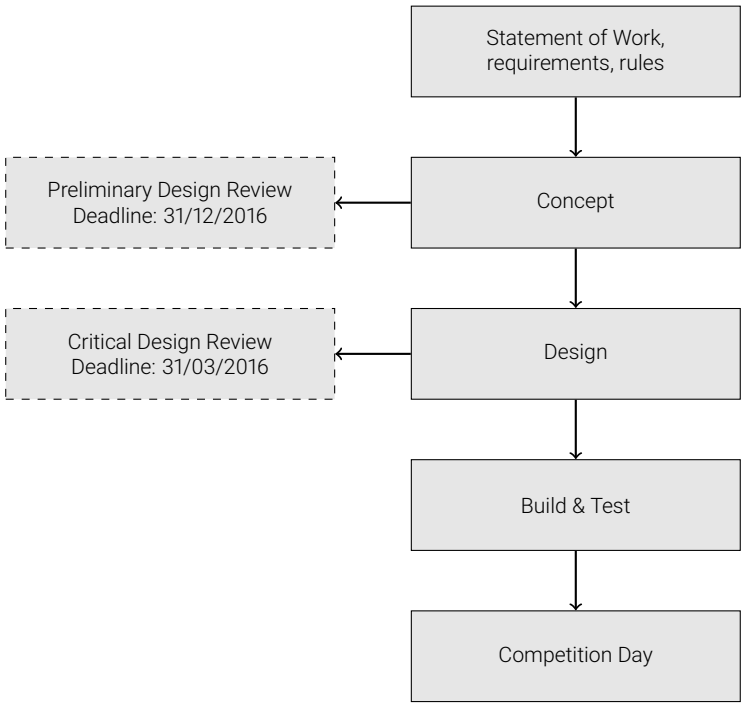

Figure 3: Development Process

The preliminary schedule for competition is shown in table 1. This includes both paperwork deadlines, and other events within the competition itself.

Table 1: Competition Schedule

Date	Activity	Deliverable
01 September 2016	Competition Launch	-
31 October 2016	Deadline for competition entries	Entry form
31 December 2016	Preliminary Design Review	PDR Report
31 March 2017	Critical Design Review	CDR Report
July 2017	Competition Event	-

3 Description of Work

The description of work contains a complete descriptions of the work that is expected to be carried out by teams. It's main subsections follows the blocks described in fig. 3. Each is split into the objectives of the work, the inputs, the outputs and a description of the task. This can be used at the top level by a team to devise its work process, in line with the deadlines given in the Competition Schedule (table 1).

3.1 Concept and Requirements

3.1.1 Objectives

i. Consolidate rover requirements

ii. Define top level architecture for the rover

iii. Create a rover design concept

3.1.2 Inputs

i. Competition Statement of Work (this document)

3.1.3 Description

In this task, teams will create an initial concept for their rover. Teams will work using this document to ensure all requirements listed in appendix D.1 are met. This stage is expected to last 2-3 months and concludes with the Preliminary Design Review, guidance for which can be found in appendix E.1.

Part of the PDR is the test plan. This section details how each of the functional requirements is going to be tested and gives a framework for performing this testing during the Build and Test phase. Tests do not need to be comprehensive or fully defined in the PDR, but they must cover the whole scope of the rover (i.e. be broad rather than deep).

3.1.4 Outputs

i. Rover concept design

ii. Preliminary Design Review (see section E.1)

3.2 Detailed Design

3.2.1 Objectives

i. Finalise a detailed design

ii. Gain confidence in the feasibility of the design

3.2.2 Inputs

i. Rover concept design

ii. PDR feedback

3.2.3 Description

In this task, teams will flesh out the concept from the previous stage, taking into account any new design decisions. Teams should consider any feedback received on the PDR and implement any recommendations.

The main goals of this stage are to finalise the design of the rover and to feasibility test components of the design which are novel or involve technology unfamiliar to the team. This testing is essential to have confidence when proceeding to the build stage and should be identified in the CDR.

Design and construction during this stage should be largely limited to prototyping and test, as teams are expected to implement feedback from the CDR during the build stage.

Near the end of this stage, teams will be invited to a meeting with a board of professionals from the space industry. The CDR report will be submitted two weeks ahead of this meeting. This allows the board to provide comments and suggestions with enough time for teams to consider their responses before the meeting itself. These meetings will be scheduled over the course of a month. Having an early CDR allows you to start the build stage sooner.

3.2.4 Outputs

i. Detailed rover design
ii. Prototype testing results
iii. Critical Design Review (see section appendix E.2)
iv. Presentation of the design given at the CDR

3.3 Build and Test

3.3.1 Objectives

i. Construct the rover
ii. Test the systems and operation of the rover

3.3.2 Inputs

i. Rover detailed design
ii. Prototype testing results
iii. CDR feedback

3.3.3 Description

Teams will carry out the construction and test of the rover as specified in the preliminary and detailed design. Teams should execute the test plan defined in the PDR (with appropriate modifications for design changes since that time) and provide a summary of how each component was tested on the competition day.

3.3.4 Outputs

i. Completed and tested rover

A Acronyms

CDR	Critical Design Review	
ITT	Invitation to Tender	
LRC	Lunar Rover Competition PDR	Preliminary Design Review
UKSEDS	UK Students for the Exploration and Development of Space	

B Applicable and reference Documents

Document	Description
ECSS-M-ST-10C Rev. 1	**Space project management** - Project planning and implementation
NEXT-LL-LES-ESA(HME)-0001	**Lunar Environment Specification** - Contains details on the expected environment during the cruise and after landing at the Lunar south pole.
ECSS-E-ST-10-06C	**Technical requirements specification** - Details the process for creating and addressing technical requirements.
ECSS-E-ST-20-07C	**Electromagnetic Compatibility** - Limits on emitted and conducted EMC for space missions are given in Annex A.
ECSS-E-ST-20C	**Electrical and Electronic** - Sections 4.2 and 5 contain good design practice for electronics operating in space.
ECSS-Q-ST-70-12C	**Design rules for printed circuit boards** - Guidelines for the production of high reliability circuit boards for space electronics.
ECSS-E-ST-31C	**Thermal control general requirements** - Good design practice for developing thermal control systems for space hardware.
ECSS-E-ST-32-10C	**Structural factors of safety for spaceflight hardware** - Important information on design margins to prevent mechanical failures in space.
ECSS-E-ST-32C	**Structural general requirements** - Good design practice for developing structures for spaceflight.
ECSS-E-ST-33-01C	**Mechanisms** - Good design practice for developing mechanisms for spaceflight.
ECSS-E-ST-40C	**Software** - Good design practice for developing robust software qualified for spaceflight.
ECSS-E-ST-50-14C	**Spacecraft discrete interfaces** - Contains information on standard interfaces used on all ESA spacecraft.
ECSS-E-ST-70-01C	**Spacecraft on-board control procedures** - Useful information on implementing command and control software for space missions.
ECSS-M-ST-60C	**Cost and schedule management** - Contains methodologies for creating schedule and cost estimates on space missions.
ECSS-M-ST-80C	**Risk management** - Contains useful information on the identification and mitigation of project and technical risks.
ECSS-Q-ST-70-71C	**Materials, processes and their data selection** - Useful information on pre-approved materials for space use.
ECSS-Q-ST-30-02C	**Failure modes, effects (and criticality) analysis (FMEA/FMECA)** - Guide to creating a FMECA; a tool used during a mission to quickly identify and diagnose failure modes
ECSS-Q-ST-30-11C	**Derating fi EEE components** - A set of guidelines for the de-rating of components to improve their lifetime and reliability.
ECSS-Q-ST-70-08C ECSS-Q-ST-70-26C ECSS-Q-ST-70-38C	**Soldering of high reliability connections** - Three guides on soldering methods for increasing reliability in harsh environments.

ECSS-S-ST-00-01C	**Glossary of terms** - A list of commonly used terms in ECSS documents.
Falcon 9 User Manual	**Falcon 9 User Manual** - Launch vehicle user guide for the SpaceX Falcon 9 rocket including the launch environmental conditions.

C Competition Rules

C.1 Competition Authority

The LRC rules are issued by UKSEDS annually. Official announcements by UKSEDS should be considered to have the same validity as these rules. UKSEDS reserve the right to alter the rules, clarify ambiguities and disqualify teams at any point from taking part in the competition, for safety reasons or otherwise. Teams that enter agree to comply with the rules, and report ambiguities or mistakes to UKSEDS.

C.2 Eligibility and Team Structure

The competition is open to UKSEDS members and students from UK universities. It has been designed to be able to work as a group project towards a degree, but other entrants are welcome. There is no limit on the number of members in a team, but there may be a limit on the attendance to the competition event. Additionally, the work should be demonstrable as being done by the team members, and not academic supervisors or other advisers.

C.3 Rover & Requirements

Teams shall comply with all requirements listed in the Technical Specification appendix D. Teams may choose to comply (or identify and explain areas of non-compliance) with the space standards listed in the Applicable and Reference Documents (appendix B).

C.4 Costs and Funding

There is no fee to enter the competition.

Teams should source funding for the project themselves, via grants from their universities, students' unions or departments. Teams who progress past the CDR will be eligible for a grant through the LRC grant pool, provided kindly by our sponsors. This money, up to 500 may be used for any aspect of the project, including the construction of the rover or transportation of the team to the test site. It will be paid in arrears after the competition event. Entries into the LRC are not eligible for the UKSEDS projects grant award scheme.

Teams entering the competition are also encouraged to search for sponsorship from commercial entities, especially those in the aerospace field. However, the competition authorities should be informed of this before any sponsorship deal is agreed, and it should be demonstrable that the majority of the work has been done by the team if technical advice is given. All sponsorship should be attributed correctly in the design review documentation.

C.5 Competition Day

The final part of the Lunar Rover Competition is the test on the competition day. This will be held at RALSpace in Harwell, Oxfordshire. The date and travel and accommodation arrangements will be released at a later date.

The majority of the tests will be carried out on the ”Moon Yard”. The specifications for this test area are defined in appendix D.3. Teams will be able to either control your rover by line of sight, or remotely from a control room. There will be a separate preparation area near to the test pit. Each team will have two opportunities to perform the mission, before and after the vibration test (see appendix D.2). Teams will draw lots to identify the order of the competition.

C.6 Scoring & Awards

The main competition is scored on the competition day, following the scoring scheme shown in the table below. The two teams with the highest points will be awarded 1st and 2nd place. If there is a tie, the winner will be the team that completed the tasks in the quickest time.

There will also be a separate award for the team who can demonstrate the most complete compliance with space standards (see Applicable and Reference Documents). Identification of non-compliance of the rover with standards will also be taken into account. This prize is awarded based upon the decision of the CDR board.

The prizes will be announced at a later date.

Phase	Category	Method	Max Score
1	Proximity to the sample site after travel from the landing site	Measured distance between landing site and sample site, points proportional to distance	250
	Amount of sample taken from the sample site	1 pt for every gram of sample taken	500
	Proximity to the landing site after travel from the sample site	Measured distance between landing site and sample site, points proportional to distance	250
2	Vibration ”shake” test	No additional points are awarded during the vibration phase	-
3	Proximity to the sample site from the landing site	Measured distance between landing site and sample site, points proportional to distance	500
	Amount of sample taken from the sample site	2 points for every gram of sample taken	1000
	Proximity to the sample site from the landing site	Measured distance between landing site and sample site, points proportional to distance	500

D Technical Specification

The technical specification given here contains all the requirements that **must** be met by a team to progress through both the PDR and CDR, and to progress to the competition day. There is an additional, separate prize for the team that best fulfils a more complete set of space standards, listed in the Applicable and Reference Documents.

D.1 Rover Requirements

Table 4: **Structure and Mechanics**

#	Requirement	Description
1.1	Mass	The rover should be limited to a mass of 5kg
1.2	Volume	The rover should fit inside a 300 x 300 x 300 mm box in its smallest configuration. After leaving the lander area, appendages may be deployed beyond this limit
1.3	Vibration Environment	The rover should be designed to survive the launch vibration environment as specified in appendix appendix D.2

Table 5: **Power and Propulsion**

#	Requirement	Description
2.1	Atmosphere	In fitting with the Lunar setting of the competition, the Rover shall use a form of locomotion that does not require an atmosphere (i.e. no aircraft)
2.2	Surface	The rover should be able to traverse an unknown surface of sand and rocks. The sand will be dry. Rocks range between 5 - 40cm. The maximum incline of the slope is 30 degrees.
2.3	Travel Distance	The maximum straight distance of travel the rover will have to cover is 60m.

Table 6: **Command and Control**

#	Requirement	Description
3.1	Communication	Communication between the operating base and the rover shall be wireless (refer to the range in the test pit specification). No time delay is added to the communication system.

3.2	Legality	All wireless communications must use UK legal frequencies, and should be used responsibly. For teams without RF experience, 2.4GHz spread spectrum are recommended to avoid interference issues (such as WiFi or Bluetooth). Teams have no access to local WiFi networks. As such, if WiFi is to be used teams must provide all the associated equipment. Advice can be found on the Resources page of the competition website.
3.3	Equipment Placement	RF Equipment may be placed at the landing sight (location of the rover start).
3.4	Kill Switch	The rover shall have an external and easily accessible manual hardware kill switch that isolates battery power from the rest of the rover.
3.5	Autonomy	If the rover has any form of of automated systems, the judges must be satisfied that sufficient safety measures are in place to prevent accidents. The rover shall have some form of remote override to stop it if it deviates from the course.
3.6	Line of sight & sensing	There will be no visual line of sight to the rover during the test. The rover should be able to detect and view its surroundings. Teams will have a single camera viewing angle (described in the Test Definition).

Table 7: **Safety**

#	Requirement	Description
4.1	Live Voltage	No exposed point or area of vehicle should carry a live voltage at any point during operation for the rover. Live voltage ¿12V. If it was less than this then lots of the tracking on low voltage digital boards would need to be covered up.
4.2	Battery	The vehicles batteries should be protected from the following conditions - over voltage, under voltage, over current, over temperature, short circuit and reverse connection. Lead Acid batteries are not allowed. The batteries shall be removable. Battery good practice should be followed (checkout the Resources page of the competition website.)

D.2 Vibration Specification

Part of the competition is to build the rover to be able to withstand a test on the vibration table at RALSpace. Vibration tables are used to simulate the conditions of a flight. Teams shall build their rovers to withstand the flight vibration environment of a SpaceX Falcon 9 rocket, which is detailed in the Falcon 9 User Guide.

Specifically, the profile that will be used at the competition is the Sine Vibration environment on page 21 of the User Guide, which is displayed in Figure 4-3 and Figure 4-4. No other vibration modes, acoustic or shock testing will be carried out on the rover. It is recommended that teams take into account both the mechanical and electrical/electronic problems associated with vibration.

D.2.1 Mechanical Interface Specification

To attach to the vibration testbed at RALSpace the rover must have an appropriate mounting mechanism. A CAD drawing of this is available on the Resource section of the competition website. If this requirement is not fulfilled - the rover will not be attached to the vibration table, and the associated points will not be available.

D.3 Test Definition

The Test Area is the "Moon Yard" at RALSpace, an outside moon simulation pit largely made up of sand and assorted rocks. appendix D.3 shows a diagram of the test area. Teams will not be aware of the exact layout or surface conditions of the test pit before arriving on the test day. A single camera feed will be made available to teams during the task from the starting position for the rover, the so-called "Lander-Cam". The target sample will be "chunks" of dry ice mixed with sand at the sample site. Note that only the dry ice mass will count towards the score. 500g of dry ice pellets will be placed into the sample area just before the start of the test. The size of these chunks is expected to be 9mm in diameter and between 1cm & 5cm in length. Teams will need to navigate from the lander position to the sample site and back to the lander position, which has a maximum straight line travel of 60m. No charging will be allowed for the rover in the test pit. Teams will be able to recharge/swap their batteries in between tests. The light conditions in the test pit are natural, although the area may be shaded by buildings or clouds.

E Deliverable Specification

E.1 Preliminary Design Review

The Preliminary Design Review is normally held at the end of Phase B of the project process defined in the Space project management standard (ECSS-M-ST-10C Rev. 1). The following excerpt is taking directly from this document, and is intended to demonstrate was is expected in a PDR.

> **Main Review Objectives fı Preliminary Design Review**
> The primary objectives of this review are:
> - Verification of the preliminary design of the selected concept and technical solutions against project and system requirements.
> - Release of management, engineering and product assurance plans.
> - Release of product tree, work breakdown structure and specification tree.
> - Release of the verification plan (including model philosophy).

It is therefore expected that you provide some evidence that you provide some information inline with this thinking. A template for the PDR has been uploaded to the competition website. It contains sections for you to insert the following information:

- Project Management
  - Assigned roles (and team roster)

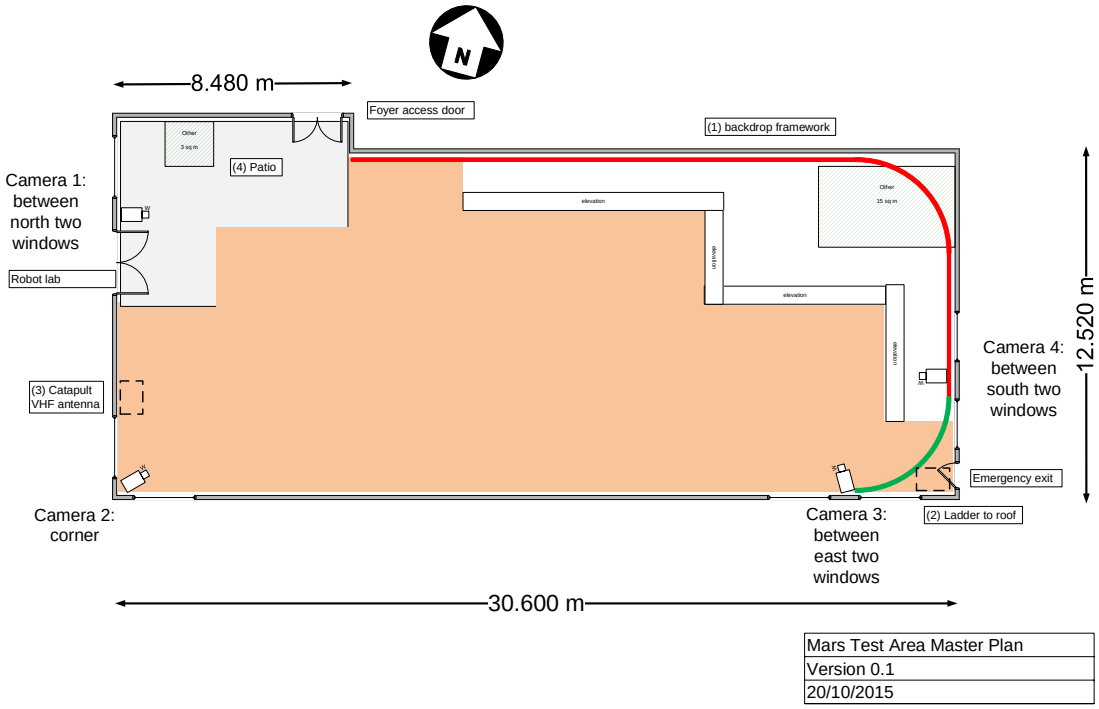

Figure 4: RALSpace Moon Yard

  - Preliminary schedule
  - Preliminary budget
  - Project risks and mitigation

- Preliminary concept:
  - Summary of requirements
  - Proposed concept for meeting these requirements
  - Brief discussion of reasons for design choices (e.g. battery type, tracks vs. legs vs. wheels etc)
  - Evidence of trade-offs in the design process

This document should be submitted by 31st December 2016 and will be marked by a small team of internal assessors. Upon receiving confirmation that they have passed the PDR, they may progress with the next stage of the competition - preparing for the CDR.

E.2 Critical Design Review

The Critical Design Review is a major milestone in the development of a space mission, and it is similarly an important obstacle in this competition. It is normally carried out at the end of Phase C (Detailed definition) of a project, and according to ECSS-M-ST-10C Rev. 1 should address the following objectives:

Main Review Objectives fı Critical Design Review
The primary objectives of this review are:

- Assess the qualification and validation status of the critical processes and their readiness for deployment for phase D.
- Confirm compatibility with external interfaces.
- Release the final design.
- Release assembly, integration and test planning.
- Release flight hardware/software manufacturing, assembly and testing.
- Release of user manual.

The following items should therefore be addressed in your CDR documentation:

- Project Management
  - Assigned roles
  - Schedule
  - Budget
  - Project risks and mitigation
  - Test plan
- Indicate any new requirements
- Indicate how requirements identified in PDR and early stages have been met
- Fully describe the mechanical, electronic and software subsystems
- Identify and address any safety risks in the design

This should be submitted to the competition by the deadline, and will be subsequently reviewed by a panel of industry experts. The panelists will then return to the teams a set of notes, with points to be addressed and clarified. A Skype call between the team and the panelists will give the team an opportunity to address any concerns raised, and if this is done sufficiently, the team will progress through the CDR. At this point the LRC grant is unlocked for the team.

A template CDR document has been uploaded to the competition website.

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UKSEDS is the UK's student space society. We provide opportunities to students who have an interest space, including workshops, competitions and our annual National Student Space Conference. We help students find careers informations at SpaceCareers.uk, and provide opportunities for students to volunteer with us.

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