Design and Testing of a Robot to Deploy a Super-Conducting Power and Communication Cable down into a Lunar PSR

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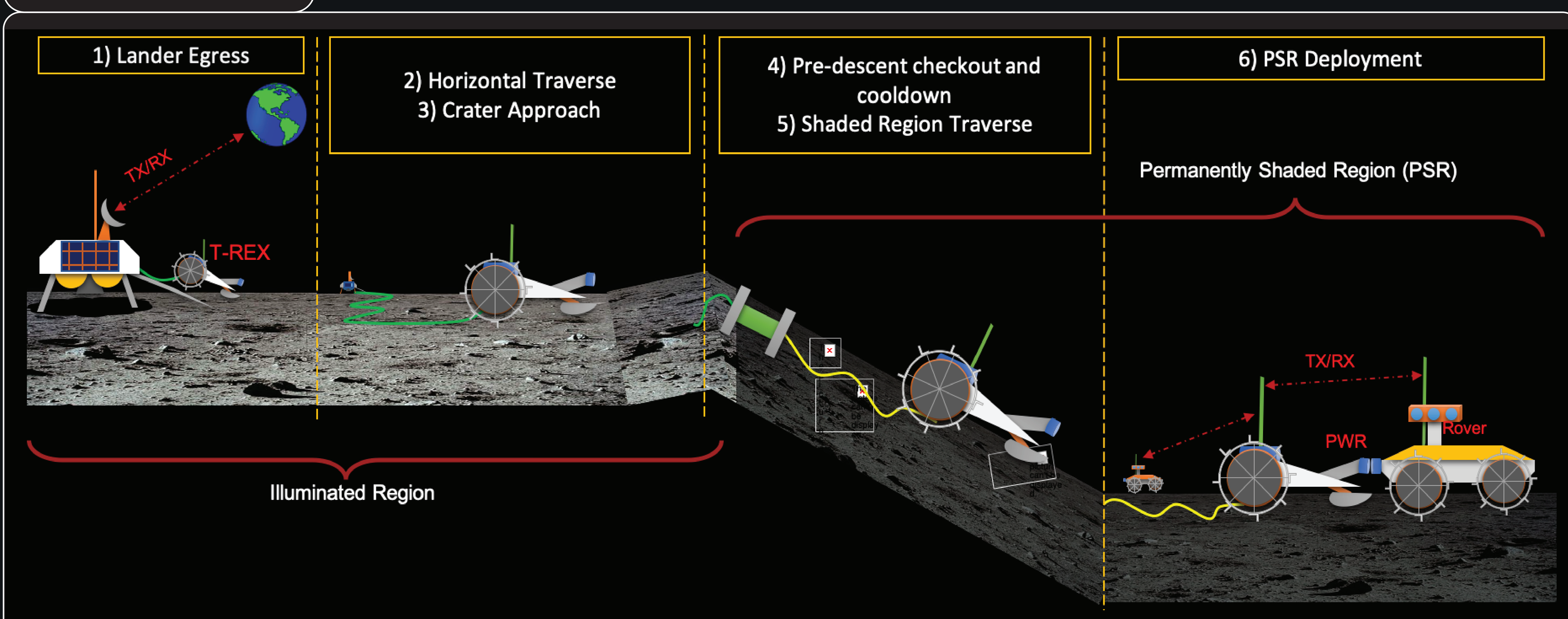
INTRODUCTION

NASA BIG Idea Competition: A team of students from Michigan Technological University (MTU) submitted a proposal to The 2020 BIG IDEA Challenge: Capabilities to study dark regions on the Moon. There were three topics : (1) Exploration of PSRs in lunar polar regions, (2) Technologies to support lunar in-situ resource utilization (ISRU) in a PSR , (3) Capabilities to explore and operate in PSRs.

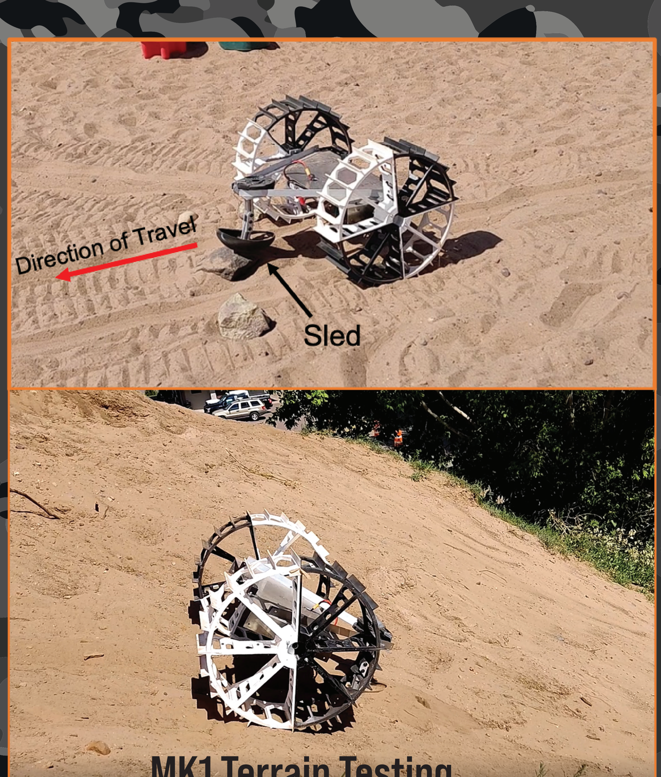
Our proposal T-REX (Tethered - permanently shaded Region EXplorer) was chosen as 1 of the 8 awardees. The project was awarded in February 2020 and will conclude in January 2021. T-REX will be designed to deploy a lightweight, superconducting cable for power and communications into a permanently shadowed region. It will be unspooled by a two-wheeled rover that traverses down the slope of the crater. After reaching its final destination, the rover becomes an electrical re-charging hub and a communications relay for other robots operating in the PSR. This technology leverages the ultra-cold temperatures of the Moon's polar shadows and insulative properties of the lunar regolith, enabling the use of super-conducting materials without active cooling systems or insulation to deploy a superconducting cable down into the PSR. The goal of the competition is to bring the technology to TRL-6 and test it in relevant environment conditions.

CONOPS

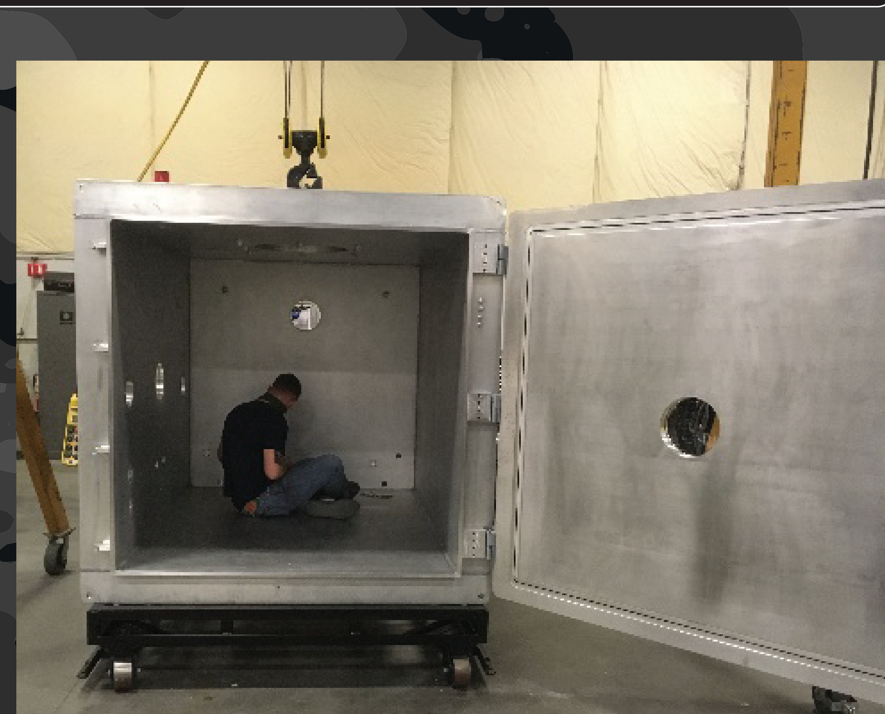


HIGH-LEVEL REQUIREMENTS

MS-01	Mission Statement	The Tethered permanently-shadowed Region EXplorer (T-REX) is an infrastructure technology demonstrator mission whose goal is to provide reliable power and data to other operations within Permanently Shadowed Regions (PSRs) of the Moon, where conventional line-of-sight radiofrequency (RF) communications and solar power generation is limited.
MO-01	Mission Objective 1	The T-REX rover shall utilize a direct connection to a CLPS lander to provide continuous power and communications to itself within a lunar PSR.
MO-02	Mission Objective 2	The T-REX rover shall provide power recharging and communications relaying for other compatible missions operating within a lunar PSR.
SC-01	CLPS Lander Deployment	The T-REX rover shall be able to sucessfully deploy from a selected CLPS lander.
SC-02	T-REX Power Provision	The T-REX rover shall be able to operate with the tether-supplied power from the CLPS lander which it is deployed from.
SC-03	T-REX Communication Provision	The T-REX rover shall be capable of two-way communication between itself and the CLPS lander over the connected tether.
SC-04	Terrain Traverse	The T-REX rover shall be able to traverse up to 2 km of variable terrain from the CLPS lander to the final deployment location.
SC-05	Tether Deployment	The T-REX rover shall be able to deploy a tether capable of transmitting 2-way communications and power.
SC-06	Mission Imaging	The T-REX rover shall be able to capture images of a crater rim, PSR slope, PSR basin, and itself during operation.
SC-07	Client Mission Power Provision	The T-REX rover shall be able to provide power to at least 1 other mission within a PSR via a direct, detachable coupling.
SC-08	Client Communication Provision	The T-REX rover shall be capable of providing two-way data passthrough from the connected mission component to the attached CLPS lander over the connected tether.

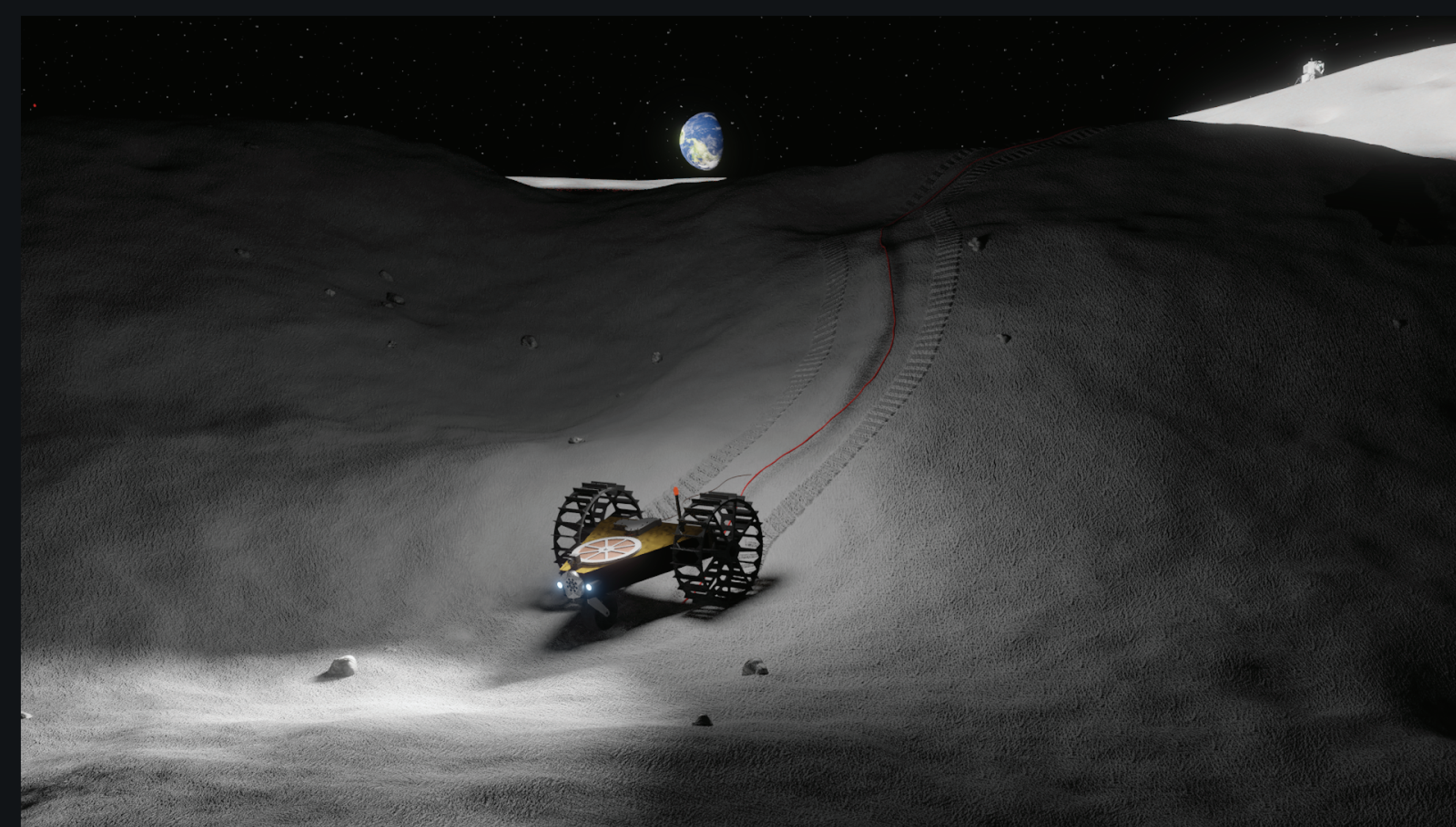


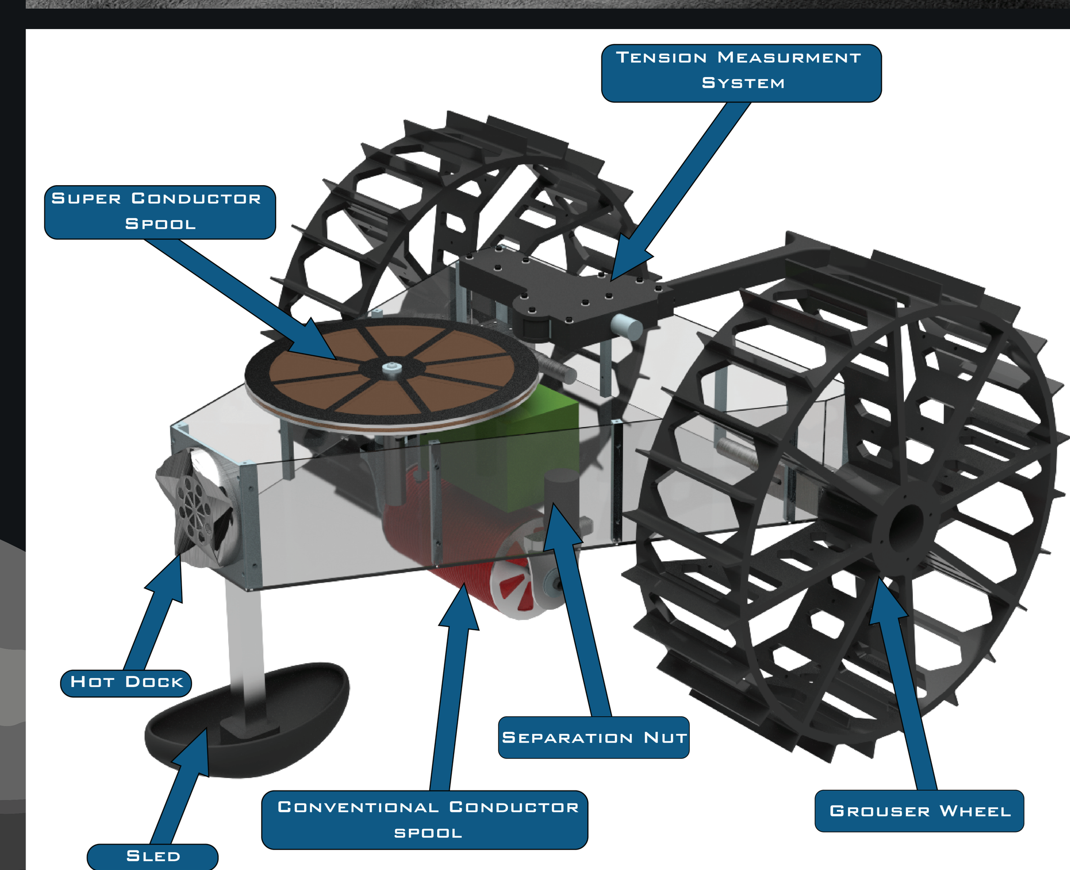
MK1 Terrain Testing


DTVAC Assembly Progress and Scale

ABSTRACT

NASA is interested in accessing and processing potential ice resources in the lunar Permanently Shaded Regions (PSRs).The PSRs have very cold temperatures due to sunlight never reaching the surface there. In addition there is no direct line of sight from Earth or to the landing location due to terrain topography. Due to this, surface operations in the PSRs have challenging power and communication constraints. NASA organized the BIG Idea competition to help get students involved to think creatively and produce solutions for operating in the PSRs and develop them to TRL-6 if possible. One possible solution to minimize battery size and communication constraints is to deploy a super-conducting power and communication cable down into the PSRs and be a power charge and communication relay point in the PSR. Power would be generated at the landing site and transferred via the cable down into the PSR. Other ground vehicles can then dock and recharge as well as have continuous communication via the relay station which then would allow less stringent constraints on the communication and power systems of the surface systems operating in the PSRs. This poster describes the operations, design and testing of the Tethered - permanently shaded Region EXplorer (T-REX) idea and the Lunar - Superconducting Access Beacon and RElay (L-SABRE) rover.





CONCLUSION & ACKNOWLEDGEMENT

CONCLUSION

The L-SABRE rover is well on its way to be developed to the point where we will be able to deploy several kilometers of superconducting cable into the PSRs. After the final tests, the technology will be close to TRL-6 and the developed testing facilities will allow other lunar technologies to be tested to TRL-6.

ACKNOWLEDGEMENTS

Senior Design team: Alex Mathias, Anthony Miller, Jacob Wolff, Mark Wallach, Sam Lakenen, Alec Mitteer, Jonathon Fritsch

Summer/Fall team: Erik van Horn, Austen Goddu, Wyatt Wagoner, Collin Miller, Elijah Cobb, George Johnson, Hunter McGillivray, Ted Gronda, Travis Wavrunek, Eric Mossner

Big Idea Challenge: Thanks to our sponsors for funding and support for the T-REX mission/L-SABRE rover

JPL: Thanks to JPL's tethered rover experts for reviewing our mission during a design review and several teleconferences.

Maxon: Provided high-quality motors to the team at affordable rates

SAS aerospace: Provided HOTDOCK power coupling interface for mutual testing purposes.

TEST RESULTS

Superconducting cable:

Current Results:

>>The SCT was able to relay power over the EPS with losses not detectable by the current lab equipment. The tether was also successfully able to relay power between superconducting and conventional conducting segments.

Future testing plans:

>>Testing the SCT in an anechoic chamber to determine noise and transmission losses. This will let us help complete the model for the tether link budget.

>>Sending video over the SCT via VDSL2.

>>Sending data and power over a 2-channel tether

Power and Communication

Current Results:

>>The EPS can meet the power requirements for the current hardware.

>>The EPS can safely distribute power to the entire system from a tether or the on-board battery pack.

>>The COM system can communicate via VDSL2 over a conventional tether, sending video feed from the rover at 90fps.

Future Testing Plans:

>>Incorporate all electrical system into PCB stack to mimic the use of cubesat hardware.

>>Modify EPS to handle up to 170W Peak Power for the new drive motors.

>>Add wireless communication hardware to rover to verify functionality as a "lunar hotspot" over VDSL.

>>Add more camera feeds to the COM hardware for better visibility during movement.

Cable Tensioner & Deployment

Current Results:

>>The Tension measurement system can maintain <5N of tension (break point: 28N/conductor path @4mm width) while unspooling a test-tether.

>>The tension measurement system was able to reduce dust ingress during testing in the sandbox.

Future Testing:

>>Add additional dust mitigation measures to stop dust ingress to the TMS but allow for the

>>Test the unspooling system during sloped descent and uncontrolled sliding,

Control & Software:

Current Results:

>>The OBC can control the rover and be commanded remotely by a "ground station".

>>The rover can operate on KubOS cubesat flight software.

Future Testing:

>>Combine all the hardware into an easily removeable stack on a raspberry pi interface

>>Migrate the raspberry pi-based hardware to a beaglebone-based hardware for clearer path to flight when migrating to flight-level cubesat hardware.

Mobility

Current Results:

>>The rover can traverse horizontal terrain composed of lunar regolith simulant while gravity offloading is engaged.

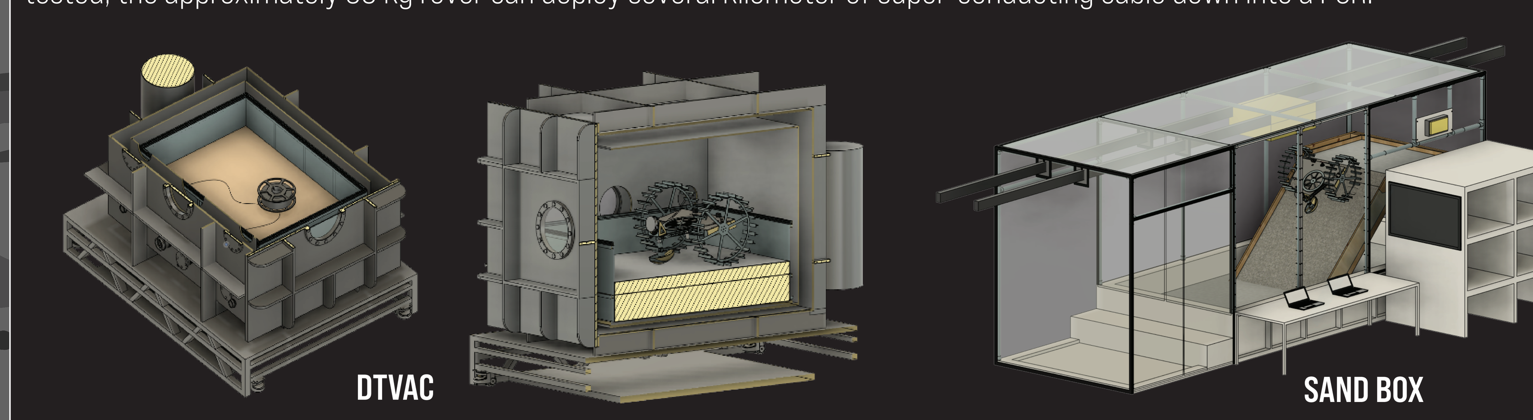
Future Testing:

>>Test rover on sloped terrain for controlled and uncontrolled descent

v>>Determine stability limits for rover when traversing terrain.

FUTURE TESTING

The mark 2 rover is designed and is being built to start testing in the 50 inch x 50 inch x 70 inch DTVAC with the superconducting cable deployment at -196°C and overall thermal systems testing as well as driving and docking in the DTVAC. When fully tested, the approximately 30 kg rover can deploy several kilometer of super-conducting cable down into a PSR.



DTVAC specs

50x53x70 inch inside thermal shroud

10-6 torr (10-4 with dust)

-196 C to 200 C

Box filled with 1500 kg of MTU-LHT-1A

2 – 10 inch windows, 16 ports

Sand box specs

14x6x1 ft sandbox in negative pressure environment with HEPA filters

1ft deep filled with MTU-LHT-1A

Gravity offloading up to 100 lbs

Slope testing possible as well as rocks and craters. Lander deck offloading testing etc.

www.huskyworks.space for info