Morphing Tank-to-Leg Modality for Exploratory Lunar Vehicles

Team Members:

Jonathan Bane: Undergraduate in Materials Science and Engineering

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Table of Contents

Additional Documents:

1.0 Quad Chart

Morphing Tank-to-Leg Modality for Exploratory Lunar Vehicles

Objectives & Technical Approach:

Goal: Engineer a modality to be utilized on the lunar south pole.

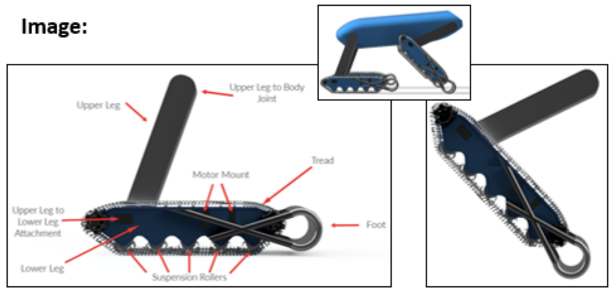
Objectives:

1. Refine design to optimize mechanical function of modality
2. Program the morphing modality
3. Allow movement on sloped surfaces 30° - 40° and on ice surfaces
4. Successfully traverse icy landscapes

Technical Approach: A morphing tank-to leg modality

Final product: A working, simple prototype of the proposed lunar modality tested against lunar-simulant environments

Image:



"Tank-mode" "Leg-mode"

Team:

Name	Major/Minor
Jonathan Bane	Major: Material Science and Engineering
Hritish Bhargava	Major: Engineering Physics
Jamison Cote	Major: Digital Media and Design, Minor: Entrepreneurship and Tech Innovation
Grayson Hall	Major: Mechanical Engineering; Minor: Computer Science
Kalin Kochnev	Major: Computer Science and Engineering
Christina Lawrence	Major: Chemical Engineering and Molecular Cell Biology
Zhiqing Li	Major: Civil Engineering
Theresa Nosel	Major: Chemical Engineering & Material Science and Engineering
Arav Parikh	Major: Computer Science
Sana Qureshi	Major: Material Science and Engineering & Applied Math
Emily Rondeau	Major: Material Science and Engineering, Minor: Mathematics
Vihaan Shah	Major: Computer Science
Elliott Trester	Major: Material Science and Engineering, Minor: Mathematics
Sabrina Uva	Major: Human Development and Family Science, Minors: Psychology and Gerontology
Anna Vladimirskaya	Major: Computer Science

Management Approach:

Team Lead: Theresa Nosel, UConn Faculty Advisors: Dr. Fiona Leek
Dr. Ramesh Malla

Schedule:

Date	Milestone
3.2.22	Order all materials
4.8.22	Build and program modality prototype
4.15.22	Drawbar pull: Simulant soil
5.5.22	Slope test
5.25.22	Mid-project report due
7.29.22	Update mechanisms and programming; load bearing capacity test
8.5.22	Drawbar pull: Vacuum chamber
8.12.22	Drawbar pull: Icy simulant soil
8.22.22	Testing at Glenn Research Center
9.24.22	Solid ice surface test
10.7.22	Drawbar pull: Cryo-chamber
10.7.22	Shake test
10.24.22	Technical Paper, Digital Poster, & Verification Testing Demonstration Files Submission

Cost:

Total proposed budget (Exact amount): **$131,463.30**

Phase 1 Total (~46%): **$61,365.70**; Phase 2 Total (~54%): **$70,097.60**

2.0 Summary Statement

The Moon is a staging ground for exploring the rest of space. The accessibility to ice and solar power makes the south pole an area of interests for scientists[1]. Ice offers oxygen to breathe and water to drink, both are key to sustaining a long-term human presence on the moon. There is also potential in using hydrogen and oxygen as a source of rocket fuel [2]. South pole highlands offer an ideal location for utilizing solar power.

Traversing the lunar south pole is particularly challenging as it is defined by harsh topography and deep craters. Highlands and lowlands are separated by steep slopes, most under 40° but some as steep as 80.21° [3]. As such, future Lunar Exploration Vehicles will require the ability to traverse 30° to 40° slopes within icy operating conditions in temperatures as low as -243 °C. Slopes greater than 30° and icy lunar regolith are not traversable by current rovers.

To allow rover mobility in this harsh, currently inaccessible lunar terrains, this team proposes a morphing tank-to-leg modality with configurations designed to overcome the challenges stated above. This morphing modality involves four appendages that are capable of functioning as a quadruped (Figure 2.1), a tank (Figure 2.2), or combination of the two (Figure 2.3). Artificial intelligence (AI) will allow it to adapt as needed to best suit the lunar environment. Combination of tank and legs has the potential to be used for obstacle avoidance and increased stability. The up-and-down stepping movement of the leg may improve motion through ice.

Figure 2.1 “Leg/Quadruped-mode”

Figure 2.2 “Tank-mode”

Figure 2.3 “Combination mode”

This morphing modality design will be tested against several lunar-simulated environmental conditions. This will include a miniature slope lab filled with sand and eventually mid-sized rocks. A hinge mechanism will allow the test slope to be adjusted to various angles between 10° and 40°. The MSL will allow for qualitative analysis of the modality’s ability to travel up and down steep slopes. To determine the morphing modality’s capabilities in icy conditions, testing will take place on a flat, icy surface (hockey rink), as well as in a chest freezer of frozen LHS-1 lunar simulant soil. Additional testing will occur in low vacuum and cryogenic environments to simulate the atmospheric conditions of the Moon. Finally, a shake table will assess the modality’s stability will be developed and tested to withstand moonquakes.

The adaptability of the morphing design makes it possible for the modality to traverse more a diverse terrain than is possible with a singular, conventional modality. Thus, this morphing modality design will enable exploration of lunar regions that have been previously inaccessible and “help NASA go forward to the Moon.”

3.0 Problem Statement and Background

3.1 Problem Statement

The aim of this project is to design a novel locomotion modality for NASA's autonomous lunar rover to tackle the unique challenges posed by the complex environment found at the lunar south pole. The focus is on overcoming the challenges associated with the traversal of steep slopes and icy surfaces. The modality will have to traverse gradients steeper than 30° to successfully ascend and descend crater walls found around the lunar south pole[4]. Within craters, the modality will have to maneuver through icy patches and endure temperatures as low as -243°C[4]. The modality must further prove itself to be a reliable, effective, and efficient in terms of not only functionality, but also particulate contamination prevention and mitigation.

3.2 Background

Historically, NASA and its international counterparts utilized a wide variety of wheel and suspension combinations for off-world use. As missions have moved to Mars, six-wheeled rovers with a rocker-bogie suspension have become the predominant design to traverse the mostly flat Martian terrain[5]. This suspension design equally distributes weight to all six wheels to minimize slip and tilt, but at the cost of limiting the rover to slopes less than 30Bostao. While an improvement over the ~20° limit of the Apollo LRVs and Lunokhod-1, it is still unsuitable for the lunar south pole[6].

The circular wheel design on the current Martian rover has seen only a few modifications from the past lunar roving vehicles. It is known to sink into loose surfaces and lacks the traction needed to traverse steeper terrain[7]. This makes slippage increasingly likely as missions move towards more rugged lunar regions with loose regolith and icy patches.

Redesign means considering off-world use of popular non-wheeled modalities seen on Earth. Carnegie Mellon's SnakeBot, for example, is a search and rescue robot that slides through debris with the help of its many mechanical joints[8]. If used on the Moon, this type of locomotion would enable the traversal of a wide variety of obstacles, albeit at a slow pace and without the capacity to carry the necessary instrumentation outlined in TX04 and TX08 of NASA's 2020 Taxonomy Report.

Boston Dynamics' BigDog, on the other hand, is a legged robot built for carrying equipment during military operations[9]. Capable of navigating 35° gradients and icy surfaces, this robot's locomotive system is a promising candidate for the lunar surface. Modifications to its weight and size are likely required to increase its slope limit and prevent tipping over during inclined travel.

Tank-like tracks introduce a form of locomotion that has already been proven successful in unfavorable terrains. Tracks have also been used in many military applications including the transportation of instrumentation and technology.

Morphing modalities involve transitioning from one method of locomotion to another without adding or removing parts. Most commonly, this transition is from wheel to leg. Currently, few wheel-leg hybrid robots exist beyond the research and development phase and those that do are limited in functionality and scope. One popular model proposed at the IEEE/RSJ International Conference on Intelligent Robots and Systems utilizes a traditional wheel where one half retracts into the other half to form a semi-circular leg (see Figure 3.1 below)[10]. These legs have the same axis of rotation as the entire wheel but at a more controlled rate of rotation thus enabling precise leg-like movements. This slight rotation, along with the translational motion provided by a sliding joint on the axle allows the legs to take measured steps across uncertain terrain. While this overarching concept is quite promising for traversing rugged surfaces, its "foot" curvature may encourage slippage on more inclined surfaces.

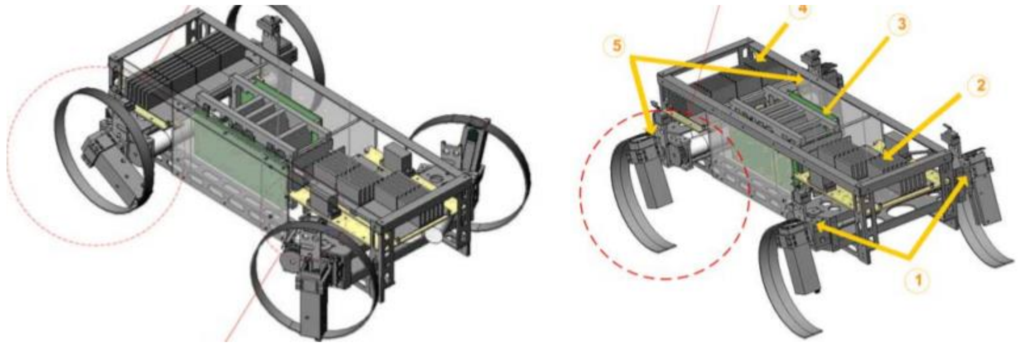


Figure 3.1. CAD drawings of robot operating in wheel (left) and leg (right) modes(10)

3.3 Overall Approach

Our proposed morphing modality (Figures 2.1 through 2.3) design aims to resolve issues the above noted modalities would likely face on the complex environment of the lunar south pole. Implementing four continuous track tank treads that can extend into legs would enable reliable navigation of a variety of terrains. Unlike the leg design illustrated in Figure 3.1, our leg design mirrors the functionality of an actual leg through the incorporation of two joints that allow the modality to walk.

For flatter environments, such as those found in crater basins, the modality will operate in "tank mode" with all four continuous tracks taking on the role of traditional wheels but with the added advantage of a tread to traverse icy and jagged surfaces.

For environments with more of a gradient, such as on the craters' walls, the morphing modality will adopt "quadruped mode" (or "leg mode"). The treads act as feet with specialized gripping patterns, repeatedly being picked up and placed down with the help of the two joints. Given each appendage operates independently, the "tank" and "leg" modes can also be used simultaneously in "combination mode." For example, the front two can be in "leg mode" while the back two are in "tank mode", thereby enabling the safe traversal of unique lunar environments.

With these three modes of locomotion, this team is confident that this morphing modality solution will enable future rovers to overcome the locomotive challenges posed by the lunar south pole.

4.0 Project Description

4.1 Technology Development

Previous lunar rover designs and movement mechanisms focused on creating solutions that excel in some terrains but may be less than ideal in others. The proposed design aims to be as multipurpose as possible without sacrificing simplicity or durability. This is made possible by using four independently operated tank-leg hybrid mechanisms. Each tank-leg consists of an upper and lower component connected by a “knee” leg. A tank tread and a specialized “foot” are built into the lower component to allow for quick switches in modality. A general-purpose configuration has each tank-leg in “tank mode,” but for steeper inclines or obstacle avoidance where this is no longer adequate, individual tank-legs can transition to “quadruped mode.” This will allow the rover to step over objects and provide a brace on very steep inclines for greater traction.

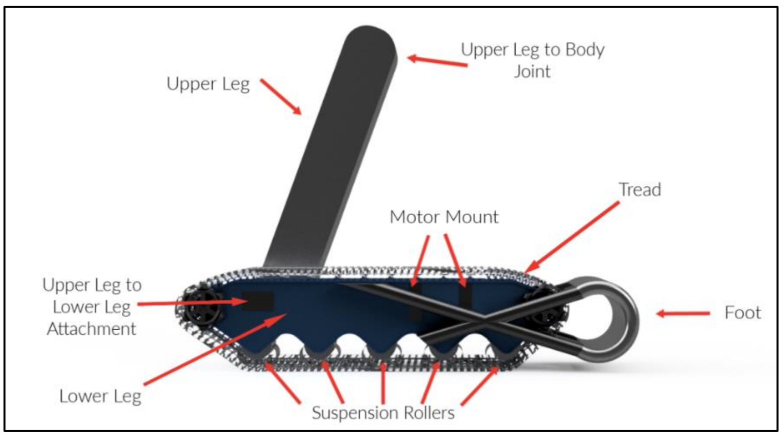


Figure 4.1 “Tank-mode” with labeled components.

Figure 4.2 “Leg/Quadruped-mode”

Figure 4.1 shows the side view of a single proposed modality, one of four, in “tank mode.” The upper leg component attaches to the body via a “hip” joint and to the lower component via a “knee” joint. There are two sets of treads on either side of the lower leg along with rollers to act as suspension on the bottom. The “feet” become useable when the leg is extended to “quadruped mode” as shown in Figure 4.2.

This unique morphing modality allows for adaptability in complex scenarios. The four independent tank/leg systems provide redundancy and versatility. For example, if the rover is in “tank mode” and encounters a rocky surface that could damage the tank treads, it would identify the obstacle and either switch to “quadruped mode” for the treads at risk or gently step over it while still in “tank mode.” To climb terrain that would not be possible with wheels alone, the rover would identify footholds in rocky terrain that would give the most traction via computer vision then convert to “quadruped mode” to climb upwards.

4.2 Lunar Architecture Plan

The morphing locomotion modality proposed will fit seamlessly into NASA’s Plan for Sustained Lunar Exploration and Development. NASA’s Plan states, “robotic lunar surface scouts are essential to validate these observations and prepare for human habitation and utilization of the moon’s rich array of resources from volatiles to minerals”[11]. The proposed morphing modality will make it possible to traverse the previously unexplored and treacherous terrains of and lunar south pole where the Artemis base camp is to be built. The modality will deploy to areas that have been identified to have potential suitability for a permanent human presence. It also will be used to survey the useable resources around the moon such as water and oxygen as per TX07.1.1 of NASA's 2020 Taxonomy Report[12].

4.3 Design Constraints and Guidelines[4]

1. Develop a novel mobility solution able to traverse:
    a. Terrain of the lunar south pole
    b. Slopes greater than 30°
    c. Icy surfaces
    d. Uneven terrain that could significantly restrict motion or impair motion completely
2. Able to support payloads and scientific instruments
3. No constraints on mass, size, power, or lifespan
4. Reach technology readiness level 4
5. Development time frame: February-June 2022 (Phase I) and June-November 2022 (Phase II)
6. Maximum budget of $180,000

4.4 Assumptions[4]

1. Ready for operation on the Moon by 2026
2. Differences in gravitational pull on the Earth versus the Moon will not affect performance
3. Operation in the extreme cold evaluated using cryogenic conditions
4. Requires minimal maintenance
5. Achieves full autonomy by time of deployment
6. Requires no physical support once on the Moon
7. Design easily transferred to NASA for further research and development
8. Compactable and durable enough for launch

4.5 Transfer Technology Potential

In addition to its intended use on the lunar surface, the proposed morphing modality may be valuable for the following earth-bound situations:

1. Carrying supplies over mountains, hills, deserts, or ice due to the modality's ability to traverse steep slopes, sandy terrain, and icy surfaces
2. Aiding in search and rescue due to the modality's extended capabilities in difficult terrains
3. Disability assistance such as using modality on wheelchairs
4. Assist scientists working in colder climates, such as in Antarctica, since the modality will be able to withstand temperatures below –150°C
5. Explore Earth's caves since the modality can travel in subterranean conditions

4.6 Technical Approach

This section describes the technical approach for Phase 1 (prototype development) and Phase 2 (verification testing on Earth).

4.6.1 Phase 1 – Prototype Development

Phase 1 provides prototype development and thorough exploration of the morphing capabilities.

4.6.1.1 Prototype Design and Construction

The initial "quadruped mode" design will utilize the Open Dynamic Robot initiative (ODRI) and their open-source quadruped design(13). This will be refined and adapted to incorporate the proposed tread and foot mechanism. The design will include sensors such as high precision encoders, an inertial measurement unit, 360-degree top-mounted LIDAR, and a front facing camera. All processing will be done onboard with an edge computing setup such as a cluster of Raspberry Pi 4s or a device from NVIDIA's Jetson series. This control software will be built off the Robot Operating System (ROS) and a high-performance language such as Rust or C++. This will be used to program the modality with AI capabilities. The prototype will be further refined and optimized by challenging the prototype with different terrains and events. AI capabilities will be programmed so the modality morphs to the "ideal" mode when certain terrain and events are detected.

4.6.1.2 Miniature Slope Lab Construction

A MSL is being modeled after NASA Glenn Research Center's Slope Lab(14) to be built in UConn's Ell-112 Lab and filled with non-silica sand. Its design will include a pivot point allowing manual adjustment to obtain incline angles of 10, 20, 25, 30, 35, and 40 degrees. It will be used to test basic movement and modality morphing of the prototype and to test slope climbing capabilities in "tank mode," "leg mode," and "combination mode." The MSL will be fitted with an OptiTrack imaging system to allow high performance optical tracking data in addition to basic visual assessment.

The MSL presents a dusty and dirty environment for the modality like that encountered on the lunar south pole. It will allow assessment of the prototype's ability to operate in a dusty environment fulfilling TX07.2.5 of NASA's 2020 Taxonomy Report(12). This testing allows prototype components to be redesigned as needed to prohibit particulate contamination.

4.6.1.3 Drawbar Pull Test Simulant Soil (Ambient)

The MSL at 0^{o} will be used to develop a drawbar pull (DP) test to qualitatively characterize the traction capabilities of the various modalities. A DP test determines the gross pulling force of a vehicle thus conveying the tractive effort of that vehicle(15)(16). Once developed, the DP test will be performed on the modality in ambient conditions in LHS-1 lunar simulant soil. Trials will be performed with by having the simulant soil packed with a consistent method. This packing method will mimic that described in the paper "Drawbar Pull (DP) Procedures for Off-Road Vehicle Testing" by Colin Creager, Vivake Asnani, Heather Oravec, and Adam Woodward. The test will be performed in "tank mode", "quadruped mode", and "combination mode".

4.6.2 Phase 2 – Verification Testing on Earth

Phase 2 provides for prototype refinement and testing of the morphing capabilities in various extreme environments.

4.6.2.1 Load Bearing Capacity Testing:

Load bearing capacity testing will determine the maximum load the morphing modality design can bear. The main limiting factors for the morphing modality design is anticipated to be the "knee" and "hip" motors used to bend and move the legs. These motors have a maximum torque output to support the prototype's body.

A Variable Linear Load Tester will be built in UConn's Ell-303 Lab. It will consist of a linear guide rail and a force plate to measure the load on the leg(17). The test will be outfitted with an extra leg to be attached to the linear guide rail. Force vs. time data will be collected until the motors no longer support the applied load. Multiple tests will be performed to determine an approximate maximum load for both an individual leg and for each variation of the modality. This testing links with TX 12.5.1 Loads and Vibration of NASA's 2020 Taxonomy Report(12).

4.6.2.2 Drawbar Pull Testing in Extreme Environments

In addition to general mobility and modality changes, the DP test developed in Phase 1 and described in 4.6.1.3 will be used to explore traction of the prototype in the following extreme environments.

Icy Lunar Simulant Soil:

Given the icy conditions anticipated at the lunar south pole, a chest freezer will be filled with LHS-1 simulant soil and sprayed with water. Once the soil freezes, the prototype will be placed inside the container for testing. A plexiglass cover will allow for viewing and containment of any simulant soil spray. Testing will be performed in "tank mode," "quadruped mode," and "combination mode."

Very Low-Pressure Environment:

The Moon has an extremely thin atmosphere and pressures at night can be as low as 2×10^{-12} torr (18). To ensure the prototype's ability to operate at low pressures, it will be placed in a vacuum chamber with a pressure of 10^{-5} torr. This test will be performed at the National Technical System's laboratory in Boxborough, MA. It will be carried out in "tank mode," "quadruped mode," and "combination mode." Comparing functionality under vacuum conditions and ambient conditions supports the modality's tolerance of harsh conditions fulfilling TX12.1.4 of NASA's 2020 Taxonomy report(12). This testing was suggested during a conversation with Robert Muller from NASA Kennedy Space Center.

Extreme Cold Environment:

Craters near the Moon's poles have temperatures recorded as low as minus 243^{o}C(4). To confirm the prototype's operation extremely low temperatures, it will be places in a cryo(therapy)-chamber at -157^{o}C for three to five minutes. This test will be performed at Caveman Cryotherapy in Farmington, CT. The temperature and time noted represents the lowest temperature and longest hold time for their cryochambers. The test will be performed in "tank mode," "quadruped mode," and "combination mode." While test temperature and time is well above the temperature of the lunar surface, this testing will provide valuable information on low temperature performance, fulfilling TX12.1.4 of NASA's 2020 Taxonomy Report(12).

4.6.2.3 Miniature Slope Lab Uneven Rocky Terrain: General Mobility, Slope Climbing and Obstacle Avoidance

The MSL will be scattered with large rocks to evaluate the effectiveness of the prototype in a rugged terrain in accordance with the autonomous system evaluation methods outlined in TX10.4.2 of NASA's 2020 Taxonomy Report(12). The information gathered from this testing will determine how well the AI system reacts to its environment.

4.6.2.4 Extreme Icy Environment Testing:

Little is known about the form of the ice expected at the lunar south pole(4). Because of this, an ice rink will be used to evaluate the prototype's ability to move over a flat, icy surface. This test will be performed at Bolton Ice Palace in Bolton, CT during two, one-hour sessions. The team recognizes a flat, icy surface unlikely on the Moon; however, it will assist in determining if additional design changes are needed to ensure success on such a terrain.

4.6.2.5 Moonquake Testing:

The Moon is known to have moonquakes, the lunar equivalent of an earthquake. Moonquakes ranging from 2 to 5 on the Richter scale have been recorded by seismometers placed on the Moon(19). To ensure the prototype can withstand moonquakes, shake tests will be performed using a shake table at UConn. Success of this test will be measured by visually determining which morphing mode best withstands shaking over an extended time. This test will provide further evidence of the modality's durability and fulfill TX12.5.3 of NASA's Taxonomy Report(12).

4.6.2.6 Long Range Travel: Drawbar Pull Testing and Slope Testing in a Larger Lunar Simulated Environment

NASA Glenn Research center's Slope Lab will host the team for large scale testing and performance analysis using their OptiTrack system, tit bed, and drawbar pull rig. These tests will be performed in lunar simulant soil. This is expected to occur end of August 2022 and will be supervised by Colin M. Creager.

4.7 Risk Assessment Chart

The following are the perceived risks to the team members and progress of the project. The team is working with UConn Environmental Health and Safety to ensure necessary safety precautions are in place including the use of personal protective equipment. Also, the team will follow the Centers for Disease Control and Prevention guidelines relating to the covid-19 pandemic.

Key:

Rare	Unlikely	Possible	Likely	Almost Certain

Event	Likelihood
Vacuum cryochamber mishap	
Cryo-chamber mishap	
Irritation from non-silica sand	
Freezer burn	
Equipment malfunction	
Electric shock from electronic parts	
Accident on flat icy surface	
Delay in supply shipping/delivery	
Irritation from LHS-1 lunar simulant soil*	

*LHS-1 is a known carcinogen.

4.8 Lifespan

This morphing modality is expected to operate for 6-8 months before experiencing a reduction in energy efficiency. While a fading power source is the primary limiting factor, inevitable wear and tear on the modality itself will also contribute to end of life. Given the harsh nature of the lunar terrain and the regolith, the treads and legs will experience erosion through constant contact with the lunar surface. Although the prototype can theoretically continue operations with only one functional modality, doing so increases the likelihood of it becoming immovable or being critically damaged.

4.9 Path-to-Flight

Phase 1 & 2, once complete, will provide proof-of-concept. Additional development and testing will be needed in preparation for the proposed modality to land on the Moon in 2026.

Not all the materials and equipment used for the prototype will survive the hardships of space travel and the environmental conditions on the lunar surface. These include, but are not limited to, the motors, accelerometer, and Polylactic Acid 3D printed parts. Acceptable replacements will be needed for full modality construction

Additional testing is also needed. Testing in a large vacuum chamber is required to demonstrate successful operation in space. Testing in a large vacuum chamber, in the presence of lunar simulant soil, is required to demonstrate successful operation on the lunar surface. Testing on icy lunar simulant soil slopes will be required. Additional testing and development of the artificial intelligence system will be needed to reach full autonomy. This fulfills TX10.4.1-10.4.3 of NASA's 2020 Taxonomy Report regarding the validation and evaluation of the modality's autonomous capabilities[(12)].

The team is not exploring packing and transporting from Earth to the lunar surface. Due to the nature of the morphing modality, it will be able to fold to occupy the least amount of space possible. Testing to simulate the impact of the turbulence of takeoff is needed. This turbulence will be more aggressive than the moonquakes already being accounted for by the team. Testing is needed to simulate travel through low Earth orbit and space from Earth to the Moon. Finally, optimization of landing configuration is required to ensure its safe arrival on the lunar surface.

To integrate this modality into a rover destined for Mars, the increased flight time to Mars required attention. It is approximately 6 months, which is 60 times longer than flight time to the Moon. Tests to determine sustainability during this longer journey are needed. The gravitational pull of Mars is $3.721 m/s^2$, which is over twice the gravitational pull on the Moon. This increase will affect the landing mechanisms and load bearing capacity. The modality may experience a shorter lifespan on Mars as its motors work harder due to this increase in gravity. Finally, Mars has a harsher surface terrain and more abrasive soil. The material used for the tread would need to be exchange for one more conducive to the Martian terrain, such as nitinol.

4.10 Scalability

Scalability allows a design to be applied to more than one situation. The unique track-leg modality proposed allows for wide ranging scalability in that it can be modified to accommodate various applications. The following is a list of scalability options:

- Each leg operates individually. This allows for addition or subtraction as needed. Future rovers could theoretically have 2, 4, or 6 morphing legs.
- The material of the leg and track can be replaced with material better suited to the environment that it will face.
- The legs can be designed to be as smaller or larger, thus changing the maximum payload and energy input requirement.
- Functional and generational scalability is possible. The leg and track can be modified for better traction on a given surface.

5.0 Capabilities Statement

5.1 Team Members and Faculty Advisors

Jonathan Bane majors in Materials Science and Engineering. He has experience working in the laboratory on materials related research and has considerable experience utilizing tools for hands-on work. His creative mindset and love for space will be applied to building and troubleshooting the mechanics of the modality.

Hritish Bhargava majors in Engineering Physics. He has knowledge of Fusion, Inventor, Solidworks, Revit, Python, PSpice, MATLAB, and Rocketry. He has experience with NASA from working on the Solar Eclipse mission where he helped build a high-altitude balloon. He previously built two high powered rockets and dozens of smaller ones with 3D printed parts. He will use his experience to design and build the hardware.

Jamison Cote majors in Digital Media and Design and minors in Entrepreneurship and Tech Innovation. He has experience in product management at a Startup Studio, User Experience Design at UConn and 3x3Insights, Robotics at First Lego League, and is an Aircraft Technician at CT Air National Guard. He is designing the morphing modality, researching testing procedures, and providing organizational support.

Grayson Hall majors in Mechanical Engineering and minors in Computer Science. He will apply his mechanical engineering and computer science knowledge to oversee data collection, sorting, and formatting from the tests performed.

Kalin Kochnev majors in Computer Science and Engineering. He has experience programming complex systems in C++, Rust, Java, and Python for personal projects and for his work at a bioinformatics lab. He has expertise in robotics, as well as prior experience managing an engineering team participating in FIRST Tech Challenges and engineering fairs. He will lead the product design team.

Christina Lawrence majors in Chemical Engineering and Molecular and Cell Biology. Throughout this project, she will obtain experience in proposal writing, verbal and written communication, and teamwork. She will document the work of the team.

Zhiqing Li majors in Civil Engineering. She has knowledge of soil testing, structural design, resiliency analysis. She will apply this knowledge to modality mechanical and electrical development as well as soil-related testing.

Theresa Nosel majors in Chemical Engineering and Materials Science and Engineering. She has previous experience with NASA through NASA Community College Aerospace Scholars, two NASA internships, and L'Space Academy Proposal writing. She is utilizing this experience as project manager for the team.

Arav Parikh majors in Computer Science. He has experience with CAD and FIRST Robotics. His is familiar with the programming languages Java, Python, and MATLAB. He is a member of the product design and testing and software development teams.

Sana Qureshi majors in Material Science and Engineering and Applied Mathematics. She has knowledge of Python, MATLAB, laboratory research, and high-level math. She has internship experience in quality assurance, failure analysis, and data visualization. Her skills from both engineering and tech industries will be applied to the creation of the modality.

Emily Rondeau majors in Materials Science and Engineering and minors in Mathematics. She has knowledge of construction and will design and build the MSL. She is looking forward to hands-on experience building the mechanisms of the modality that will allow it to function as intended.

Vihaan Shah majors in Computer Science. He has experience with motion planning and the programming languages Python, Java, and MATLAB. He will use his knowledge to create the hardware and software of the modality.

Elliott Trester majors in Materials Science and Engineering and minoring in Mathematics. He works in the Pratt & Whitney Center for Additive Manufacturing Lab. He will work on design of the prototype and incorporate innovative metal additive manufacturing technology.

Sabrina Uva majors in Human Development and Family Sciences. She has experience analyzing statistics and data in the Stamford Startup Studio and through her funded research project. She applies her experience to the NASA project by contacting Subject Matter Experts, editing written work, and going to testing sites.
Anna Vladimirskaya majors in Computer Science. She is an undergraduate research assistant at the nanoelectronics lab and has experience in robotics. Using her prior knowledge of electronics and software, she will work on programming and engineering the modality.

Dr. Fiona Leek is the primary faculty advisor for the team and is a professor in the Materials Science and Engineering Department at the University of Connecticut. Dr. Leek brings years of industry experience in polymer science to the team as well as insight for how to approach problems in practical and effective ways. She supports the team's independence and encourages ways for each member to learn new skill sets. She is aware of equipment and capabilities on campus, provides vital insight and suggestions into testing, and offers support in data collection and organization.
Dr. Ramesh Malla is a key faculty advisor and is a professor in the Civil and Environmental Engineering Department at the University of Connecticut. He has spent nearly 4 decades researching orbital and lunar structures. He offers the team valuable insight for conducting research as well as his connections in industry and NASA. He was a founding member, and served as the UConn Campus Director for 10 years, of the CT Space Grant College Consortium. Currently, he is serving as the Institutional PI/Lead from UConn for the NASA STRI research institute, *Resilient ExtraTerrestrial Habitats Institute.*

5.2 Relevant Facilities Available

Bolton Ice Palace in Bolton, CT will be used for icy surface testing. The facility has been contacted and is aware of our intended use.
Caveman Cryotherapy in Farmington, CT will be used for cryogenic testing. The facility has been contacted and is aware of our intended use.
The Department of Materials Science and Engineering undergraduate labs are available for the team to use. These labs are on the University of Connecticut Storrs' campus in the Engineering ll building. Lab 303 is where the building and storage of the modality will occur. Lab 303D contains an UltiMaker FFF 3D printer, which is available to the team to print parts to be used in construction of the modality. It also contains a large fume hood which will accommodate the lunar simulant testing enclosure. Lab 112 will house the miniature slope lab.
NASA Glenn Research Center in Cleveland, OH has a lunar simulant soil filled slope lab with an OptiTrack system, tilt bed, and drawbar pull rig. The facility has agreed to host team members for four days of testing under the supervision of Colin M Creager.

6.0 Timeline

Total timeline: February 22, 2022 – November 18, 2022

Phase 1: February 22 – May 25

TASK	START	END
Phase 1: February 22 - May 25		
Ordering material	2/23/22	3/2/22
Building modality prototype	2/23/22	3/30/22
Programming basic maneuvers	2/23/22	3/30/22
Verifying basic manuevers capabilities	3/23/22	4/8/22
Programming AI capabilities	3/10/22	3/30/22
Building MSL	3/1/22	3/11/22
Set up opertation of optitrack imaging system	3/14/22	3/21/22
Construct & install fume hood enclosure. Fill with simulant soil	3/14/22	3/21/22
Drawbar pull test construction & test method development	3/21/22	3/31/22
Redesign of prototype in response to test results	4/4/22	5/20/22
Prototype mobility, slope climbing, and drawbar pull testing in MSL	4/4/22	4/29/22
Drawbar pull testing in simulant soil	4/18/22	4/29/22
Testing overflow time	5/2/22	5/20/22
Writing of update report	4/25/22	5/25/22
Update report due		5/25/22

Phase 2: June 24 – November 18

TASK	START	END
Phase 2: June 19 - November 18		
Order Materials	6/24/22	7/4/22
Redesign of prototype in response to test results	7/1/22	7/29/22
Load bearing capacity test construction and method development	7/7/22	7/13/22
MSL rocky terrain testing	7/18/22	8/4/22
Load bearing capacity testing	7/18/22	7/25/22
Low pressure environment testing (low vacuum testing)	8/1/22	8/3/22
Icy simulant soil testing	8/8/22	8/12/22
Large MSL testing at Glenn Research Center	8/22/22	8/26/22
Extreme icy surface testing (ice rink)	9/5/22	9/16/22
Extreme cold environment testing (cryo chamber)	9/12/22	9/23/22
Moonquake testing (shake table)	9/26/22	10/7/22
Testing overflow time	10/10/22	10/24/22
Writing technical paper	9/19/22	10/24/22
Preparing presentation and digital poster	10/10/22	11/14/22
Technical Paper and Demonstration Due		10/24/21
Presentation and Digital Poster Due		11/14/22
NASA Big Idea Challenge Forum	11/15/22	11/18/22

7.0 Detailed budget

7.1 Direct Labor

Other Personnel:

One undergraduate student will work full time as a summer intern for seven weeks at a rate of $740 during the beginning of Phase 2. Since this is a project for NASA, the rate is based on rates for a NASA undergraduate intern. The intern will be responsible for tasks outline in section 6, Phase 2, from June 24 through August 12.

Given the uncertainty of obtaining Phase 2 funding, an undergraduate student may not be available. If so, this same funding will cover 15 hours/week for one graduate student during the same period. The graduate student selected will be familiar with the programming language used to control the modality and will continue to test its capabilities at the University of Connecticut, Storrs campus.

Personnel	Rate	Phase 1	Phase 2	Total P1	Total P2	Total
Student	$740/week	0	7 weeks	0	$5,180	$5,180
Total				**0**	**$5,180**	**$5,180**

7.2 Fringe Benefits

The fringe rate is 22% for students at the University of Connecticut.

Personnel	Rate	Phase 1	Phase 2	Total P1	Total P2	Total
Fringe	22%	0	Of $5,180	0	$1,139.60	$1,139.60
Total				**0**	**$1,139.60**	**$1,139.60**

7.3 Equipment

An Optitrack system will be purchased for the MSL. This system will capture the motion of the modality, how far it actually moves versus how far the programming of the modality thinks it moved, and sinkage.

Item	Cost per item	# of items	Phase 1	Phase 2	Total P1	Total P2	Total
Optitrack	$6800	1	1	0	$6,800	0	$6,800
Total					**$6,800**	**0**	**$6,800**

7.4 Domestic Travel

Travel expenses are needed for 15 team members and 2 faculty advisors to attend the forum in Pasadena, California from November 15 – 18, 2022 (Phase 2). The costs are evaluated with the team arriving one day before the beginning of the forum (November 14)

Cost category	Rate	# of People	Total
Registration	$550/person	17	$ 9,350
Airfare	$350/person	17	$ 5,950
Lodging (4 nights)*	$75/night x 4 nights	17	$ 5,100
Meals & incidental expenses (4.5 days)	$50/day x 4.5 days	17	$ 3,825
Ground transportation	$40/person	17	$680
Total			**$24,905**

*Sharing rooms with another 1-2 team members may occur.

7.5 Other Direct Costs

This table covers the materials and supplies needed. Costs include building and refining the prototype, creating the MSL and DP rig, and various other testing supplies. The bulk of the expenditures will occur in Phase 1.

Item	Total P1	Total P2	Total
Miniature Slope Lab			
Wood	$360	0	$360
Small supplies	$120	0	$120
Silica-free sand	$195	0	$195
Prototype			
Vacuum grade motors & mechanical components	$3,000	$13,000	$16,000
Motors and encoders	$10,034	1,000	$11,034
Final product—raw materials and manufacturing	$9,478	0	$9,478
Computing, sensing, and motor control	$6,236	0	$6,236
Power supplies and batteries	$3,461	0	$3,461
Tools	$2,049	0	$2,049
Wires and misc. electronics	$2,025	0	$2,025
Prototyping— raw materials and manufacturing	$1,395	0	$1,395
Mechanical components, fasteners, and connectors	$254	0	$254
Tread	$1,000	$1,500	$2,500
Other			
Simulant soil	$3,500	$7,000	$10,500
Containers for simulant soil	$30	$30	$60
Respirators	$400	$400	$800
Drawbar pull equipment	$950	0	$950
Load capacity equipment	$2,000	0	$2,000
Chest freezer	0	$600	$600
Total	**$46,487**	**$23,530**	**$70,017**

7.6 Testing Costs or Facilities Rental

These facilities are to be used in Phase 2 for various testing conditions and data collection. NASA Glenn Research Center is waving facility and equipment usage costs for the duration of the team's involvement.

Facility	Testing	Cost	#	Phase 1	Phase 2	Total
Bolton Ice Palace	Icy surface testing	$300/hour	2 hours	0	$600	$600
Caveman Cryotherapy	Cryogenic testing	$20/session	6 sessions	0	$120	$120
Glenn Research Center	Slope test, DP testing, and OptiTrack	$0/day	4 days	0	4 days	$0
Total				**0**	**$720**	**$720**

7.7 Services

NTS in Boxborough, MA is a 3rd party testing facility providing low vacuum testing. According to the quote provided, cost includes set up, one day of testing, and a test report.

Service	Cost	#	Phase 1	Phase 2	Total
Low vacuum testing	$5000	1	0	$5,000	$5,000
Total			**0**	**$5,000**	**$5,000**

7.8 Subawards:

These funds are excluded from the total amount being requested from this proposal. Upon receiving funding for Phase 2, the University or Connecticut's Engineering Deans Office will provide the team with up to $10,000 for team members to spend four days slope testing at NASA Glenn Research Center. This is tentatively scheduled for the week of August 22. Funds include travel, transportation, housing, and food. Food will be $50/person/day. The exact number of people traveling will be determined closer to the travel date and is dependent on their method of travel (i.e. airfare or car/carpooling).

7.9 Other

Additional funds are requested to cover shipping and handling costs for materials and equipment.

Expense	Phase 1	Phase 2	Total
Shipping and handling funds	$2,500	$3,250	$2,250
Total	**$2,500**	**$3,250**	**$5,750**

7.10 Total Direct Costs

Total direct cost = 7.1 + 7.2 + 7.3 + 7.4 + 7.5 + 7.6 + 7.7 + 7.9
Total direct cost = $119,511.60

7.11 Indirect Costs

7.11.1 University Indirect Costs (Phase 1 and Phase 2)

$11,952: ($5,579 in Phase 1 and $6,373 in Phase 2)

For this project, the University of Connecticut has dropped its indirect cost (IDC) rate from 66% to 10%. For Phase 1, these are calculated at 10% on Total Direct Cost bases. For Phase 2, these are calculated at 10% on a Modified Total Cost bases (excluding services and subcontracts/subawards).

Cognizant Agency (Audit and Federal Cost Rate Approval Authority)
U.S. Department of Health and Human Services
Division of Cost Allocation
26 Federal Plaza, Room 41-112
New York, NY 10278
Contact: Mr. Darryl W. Mayes, Director; Telephone: 212-264-2069

7.11.2 Space Grant Indirect Costs (Phase 2)

6,373 (Phase 2)

For Phase 2, this is calculated at 10% on Modified Total Direct Costs to manage the Phase 2 funds.

7.12 Total Direct and Indirect Costs

Total = 7.10 + 7.11.1 + 7.11.2
Total - $131,463.30

7.13 Budget Spreadsheet

Description	Rate	Phase 1 1/1/22 - 6/30/22	Rate	Phase 2 7/1/21 - 11/30/22	Total
A. Direct Labor - Other Personnel					
Summer Student		$ -	100%	$ 5,180.00	$ 5,180.00
Subtotal Other Personnel		*$ -*		*$ 5,180.00*	*$ 5,180.00*
B. Fringe Benefits					
Students	22%	$ -	22%	$ 1,139.60	$ 1,140.04
Subtotal Fringe		$ -		$ 1,139.60	*$ 1,139.60*
Total Labor Costs (A+B)		$ -		$ 6,319.60	$ 6,319.60
C. Direct Costs - Equipment (any individual item over $5,000)		$ 6,800.00		$ -	$ 6,800.00
D. Direct Costs - Domestic Travel		$ -	100%	$ 24,905.00	$ 24,905.00
E. Other Direct Costs					
Materials and Supplies		$ 46,487.00		$ 23,530.00	$ 70,017.00
Testing Costs or Facilities Rental		$ -		$ 720.00	$ 720.00
Consultants		$ -		$ -	$ -
Services		$ -		$ 5,000.00	$ 5,000.00
Subcontracts/Subawards				$ 10,000.00	$ 10,000.00
Other		$ 2,500.00		$ 3,250.00	$ 5,750.00
Total Other Direct Costs (E)		*$ 48,987.00*		*$ 42,500.00*	*$ 91,487.00*
F. Total Direct Costs (A+B+C+D+E+F)		$ 55,787.00		$ 73,724.60	$119,511.60
Modified Total Direct Costs, if applicable		$ 55,787.00		$ 63,724.60	$119,511.60
G.i. University Indirect Costs (Required for Phase I & Phase II)	10%	$ 5,578.70	10%	$ 6,373.00	$ 11,951.70
G.ii. Space Grant Indirect Costs (Phase II only)			10%	$ 6,372.46	$ 6,372.46
H. Total Direct and Indirect Costs (F+G)		$ 61,365.70		$ 70,097.60	$131,463.30
% of Total Budget (Phase I should be ~46%; Phase II should be ~54%)		*46.68%*		*53.32%*	

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