Northeastern University – Students for the Exploration and Development of Space

Proposal for NASA's 2020 Big Idea Challenge

SCOUT and DOGHOUSE

Team Members:
Jared Brauser, Paige Butler, Lindsay Euston, Dylan Gates, Elise Johnson, Ganesh Kolli, Jake Lynn, Julian Morgen, María Belén Ou, Jake Rutstein, Jack Tuthill, Ben Zinser, Andris Zonies

Advised by:
Professor Alireza Ramezani, Ph.D.
Professor Taskin Padir, Ph.D.

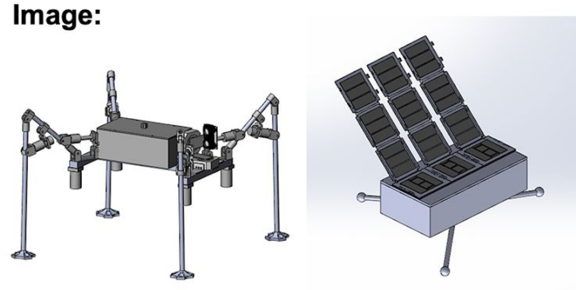
1. QUAD CHART

SCOUT and DOGHOUSE

Objectives & Technical Approach:

SCOUT, in conjunction with support module DOGHOUSE, is a platform for gathering data in, and creating a map of unexplored terrain. SCOUT was designed to navigate easily through the challenging lunar environment, and to adapt to whatever environment it may find within a PSR. DOGHOUSE was created in order to solve both the power collection and communications challenges posed by the PSR environment.

Image:



Team:

- Andris Zones, Team Lead
- Julian Morgen, Navigation
- Paige Butler, Testing
- Ganesh Kolli, Electronics
- Jake Lynn, DOGHOUSE
- Lindsay Euston, Communications
- Belén Ou, Mobility
- Jack Tuthill, Support
- Ben Zinser, CAD
- Jake Rutstein, CAD
- Elise Johnson, Support
- Dylan Gates, Electronics

Schedule:

Late February: Begin SCOUT fabrication
Mid-March: Begin SCOUT assembly
Mid-April: First In-Regolith testing
Early June: Begin DOGHOUSE fabrication
Late June: Begin DOGHOUSE assembly
July: Full systems testing

Cost:

We propose a total budget of $90,889 to build SCOUT and DOGHOUSE. The mass of the prototype will total 13.137 kg.

2. SUMMARY STATEMENT

NASA's first missions to the moon landed astronauts on hostile terrain. They found a layer of porous and abrasive dust covering unpredictable and uneven terrain, unaffected by any form of erosion. This environment poses great challenges in traversing the lunar surface, particularly in the permanently shadowed regions (PSRs) at the moon's South Pole. Based on measurements from the Lunar Reconnaissance Orbiter, the regolith here will likely be even more porous, but most other mechanical characteristics remain uncertain. However, these regions are also a site for valuable in-situ resource utilization (ISRU), as their constant cryogenic temperatures likely cold-trap water [1]. The uncertainty in mechanical and chemical properties must be remedied to pave the way for ISRU programs in PSRs. Initial exploration is needed to map out the mechanical and chemical characteristics of the regolith in PSRs to prepare for future missions. To address this problem, we propose the Surveying Craft for Observing Unexplored Terrain (SCOUT), an adaptable, legged mobility system for collecting data in PSRs. SCOUT will carry sensing equipment into PSRs and combine data it collects with position data and terrain LiDAR scans.

The system is split into two parts, totaling 13.137 kg. The first is the main rover, SCOUT. The second is its support station, the Deployable Out-of-crater Generator for Holding and Utilizing Solar Energy (DOGHOUSE). SCOUT is a four-legged rover capable of carrying at least 1.8kg of sensing equipment into a PSR. Its legged design will allow it to traverse the varied lunar terrain it may encounter during its mission. As it explores, it will create 3-D scans via LiDAR and combine them with accelerometer navigation values to create a map of the terrain. It will stop regularly to collect data and overlay that data onto the map to create a full view of the PSR. To protect from damage by the regolith, the LiDAR sensor will be shielded with a polycarbonate lens.

DOGHOUSE is a deployable solar power collection and communications relay station. DOGHOUSE will provide a line of sight between SCOUT and the lander by receiving IR communications from SCOUT, then relaying that information to the lander using WiFi. Additionally, DOGHOUSE will collect solar energy while SCOUT is taking data within the crater. Following an excursion, SCOUT will return to the edge of the crater to charge its battery using an inductive coupling wireless charger.

Before SCOUT enters the PSR, DOGHOUSE will be deployed on the edge of the crater, allowing it to gather solar energy while SCOUT is in operation. It will store this energy and recharge SCOUT when it returns from the crater. This support station will also serve as a communications relay, receiving line of sight IR communications from SCOUT and relaying them via WiFi signal to a Commercial Lunar Payload Services (CLPS) lander.

To validate the design of the system, we propose a full test prototype and a lunar simulant testbed. The prototype will be tested through the full CONOPS of the mission in Earth conditions, beginning with deployment from the lander to the lunar surface and deployment of DOGHOUSE. The rover's mobility would then be tested on flat regolith and up to a 15° incline. DOGHOUSE would be tested on its ability to receive and relay signals, gather solar power, and charge SCOUT. Building this prototype will cost $90,889 with outside testing, and $78,289 without it. Our team will utilize the manufacturing capabilities of Northeastern's Mechanical Engineering Capstone Lab and fiber composite 3D printer to minimize manufacturing costs. Workspace for testing and fabrication will be provided by the University at no extra cost.

3. PROBLEM STATEMENT AND BACKGROUND

Past missions to the surface of the moon revealed the pervasive and inescapable presence of dust. Fine-grained regolith clung to helmets and lenses, and it wore through three layers of kevlar on an astronaut's boot during the Apollo missions [2]. The abrasiveness of regolith presents an obstacle to anything that needs to move through it without being eroded, as well as anything intended to operate for an extended period of time on the lunar surface. In addition, the dust storms that form on the barriers between lit and shadowed regions due to electrostatic repulsion present a further hazard to inadequately shielded systems [3]. Overcoming the hostility of the dusty environment on the lunar surface is critical to the success of any surface mission.

In addition to the challenges presented by the lunar regolith in intermittently or near-permanently lit regions of the moon's surface, a mission with the intent of exploring a PSR encounters additional obstacles. The near-total darkness in PSRs due to the oblique angle of the sun across the lip of certain craters presents difficulties in navigation and power generation, as anything that enters the complete darkness will be unable to utilize solar energy or rely on traditional image-based autonomous navigation. Systems within craters will also not be able to rely on line of sight to a lander; the rim of the crater forbids methods of communication that rely on a direct line of sight, including IR. Additionally, the temperature in a PSR, generally between 25 and 70 Kelvin, is hostile to batteries, other electronics, and structural components and materials [4].

Not only are PSRs environmentally challenging, but they are also almost completely unknown in terms of regolith composition and terrain. The Lunar Reconnaissance Orbiter's cameras were designed to image well-lit sections of the lunar surface, not the darkness of shadowed regions. The image data the LROC Narrow Angle Cameras can provide is enough to hint at the general shape of the terrain in a PSR but is not a high enough resolution to base future mission plans on. The Lyman Alpha Mapping Project sheds some light on the composition of the regolith, indicating that the soil is "fluffier" in dark regions, and may contain higher concentrations of water ice than the exposed illuminated surface, but some craters show no detectable signs of water at all [5]. Any mission to a PSR will require further knowledge concerning the navigability and ISRU potential of possible landing sites.

To address this problem, a lightweight system is needed for quickly collecting data over small regions of a PSR. It should be compatible with a CLPS lander, which means it must weigh less than 15 kg in total. It should be able to carry a variety of sensing equipment into a PSR to map out the mechanical and chemical properties of the regolith. The rover will also need a source of power that can solve the lack of solar power in PSRs. Additionally, the system needs to be able to communicate with the lander when a line of sight is not available in the PSR. To address the terrain challenges that occur within the PSR, the mobility system must be able to adapt to mechanical property unknowns. It must limit the effects of lunar dust abrasion and must react to avoid obstacles as it moves.

4. PROJECT DESCRIPTION

4.1. SCOUT

4.1.1. Structural Design

SCOUT's frame will be designed in the shape of an H, as shown in Figure 1. The legs will be mounted on the corners of the body, and all electronics will be housed in a single, 182 by 104 by 79.5 mm central box. SCOUT's LiDAR system will be mounted on the front of this system to give it a full view of where the rover is going. In addition to the parts integral to SCOUT, the frame will also have attachment points for its interface with the CLPS lander and with DOGHOUSE. DOGHOUSE will be secured underneath SCOUT until it is deployed at the edge of the crater. Attachment points to DOGHOUSE will be located along the central beam of the lander, while the attachment points to the lander will be located at the four corners, near the legs.

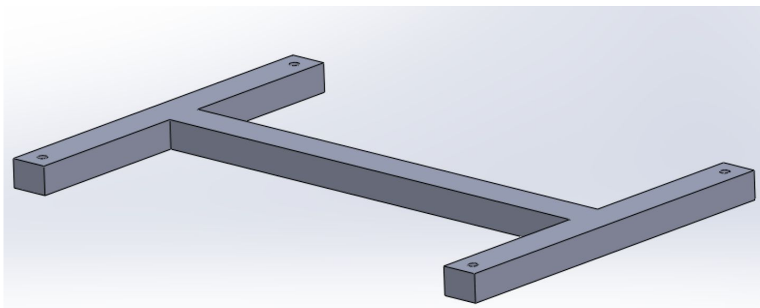


Figure 1. SCOUT's body frame shape

To fully design the frame, finite element analysis will be performed with loads set by the conditions the rover will experience during launch. To set baselines for these loads, Astrobotic's Peregrine lander has been selected as an example CLPS lander. Based on the data that Astrobotic provides, SCOUT is expected to experience between -2g and 6g of axial load and between -2g and 2g of lateral load. Additionally, the rocket's launch will create a shock spectrum with 100 g at 100 Hz and 2,800 g at 1,500 Hz and 10,000 Hz [6]. These forces will set the requirements for us to design the rover's frame to ensure that SCOUT's body is constructed with the necessary strength to survive launch.

To ensure that this structure is both lightweight and sufficiently strong, high strength carbon fiber has been selected as the structural material of choice on the rover. Based on current models, the body will weigh 0.75 kg when constructed with this material, including the mainframe and its attachment points to other systems.

4.1.2. Attachment to the Lander

Based on the data available on Astrobotic's Peregrine lander, SCOUT is expected to experience a shock response spectrum given in section 4.1.1.1 of the paper. To protect the SCOUT's fragile components, it will be attached to the lander with four vibration dampers at the four corners of the H-shaped body frame. During the flight, SCOUT will be held with its legs in the stowed position, as shown in Figure 2, keeping SCOUT safely within the bounds of the payload envelope for the duration of its journey to the lunar surface.

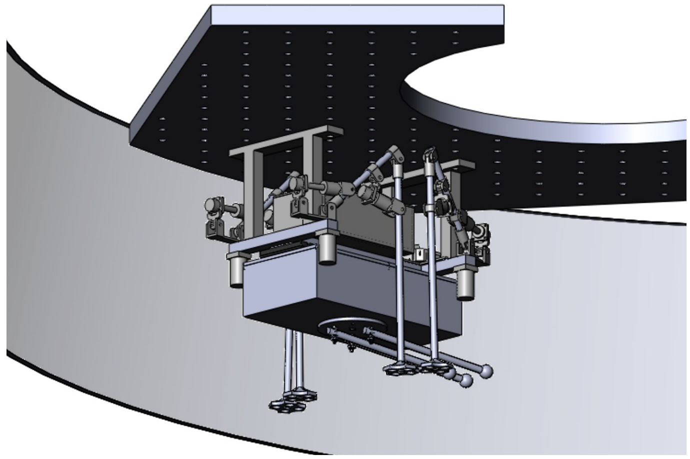


Figure 2. SCOUT's positioning for flight and landing

To release from the lander, a fully space ready SCOUT would make use of four hold-down release mechanisms (HDRMs) at each of the corner attachment points. The HDRMs would be simultaneously released via an electric pulse to allow SCOUT to drop to the lunar surface. However, as HDRMs are cost-prohibitive for a prototype, testing will be performed with bolts released by hand.

To make a controlled descent to the lunar surface, SCOUT will use a system of pulleys and flexible tethers on the mounting plate of the lander, a portion of which is shown in Figure 3. Four pulleys will be bolted to the mounting plate above the four corners of the body's frame. The flexible tethers will be spooled around each pulley. When the bolts attaching SCOUT to the lander are removed, SCOUT will be free to descend in a controlled manner using the guided pulley system.

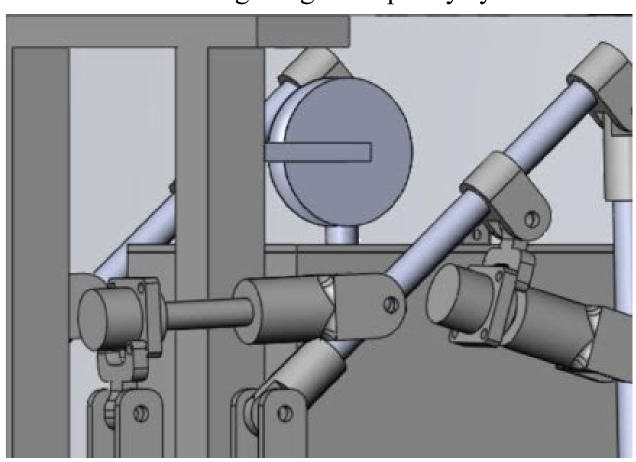


Figure 3. Attachment to lander

4.1.3. Legs

Several mobility designs were considered when choosing the most efficient method to explore PSRs. Of these designs, wheeled and legged systems were analyzed to find the most suitable mechanism. Traditionally, wheeled systems have been the standard for lunar and Martian rovers, since the requirements for these systems are better understood. However, wheels require a continuous path of travel. Due to the general uncertainty surrounding PSR terrain and regolith porosity, they are not ideal. Generally, wheeled systems are unsuitable for use in an irregular and uneven terrain due unless accompanied by complex and mass-inefficient suspension mechanisms due to their shortcomings in grounding pressure, slipping, and sinkage. PSR mobility systems must be prepared for any environment and wheels are not able to adapt to different ground conditions. In contrast to wheel driven vehicles, legged systems offer a greater range of mobility and are able to actively adjust their center of gravity to regulate stability. Additionally, their feet can be customized and the legs can avoid undesirable footholds to prevent sinkage. When designing a SCOUT, a quadrupedal system was selected. Four-legged robots are statically stable and can be programmed to walk a single leg at a time to maintain three points of contact with the surface. These features make them suitable for exploration into PSRs. Potential drawbacks of the design include a higher power draw, decreased movement speed, and complex controls. However, these factors were considered during the design phase. Legged systems continuously draw power while standing. Therefore, to decrease their power consumption, self-locking linear actuators were selected so that there is no power usage when they are still. However, the stepper motors will continuously draw power. Legs, in terms of controls, also have a higher computational power draw. While having a slow rover will limit the area that can be explored, it allows the robot to move more carefully, which is important in unknown terrain.

4.1.3.1. Joint Design and Leg Segment

For SCOUT to achieve the desired level of mobility, a legged system was designed with three axes of rotation about two main joints; the hip and the knee. Coupling to SCOUT's mainframe, the hip joint consists of a servo motor that rotates the entirety of the leg about the θ axis while a linear actuator, also at the hip joint, is able to move the upper leg segment in the R direction as seen in Figure 4 below.

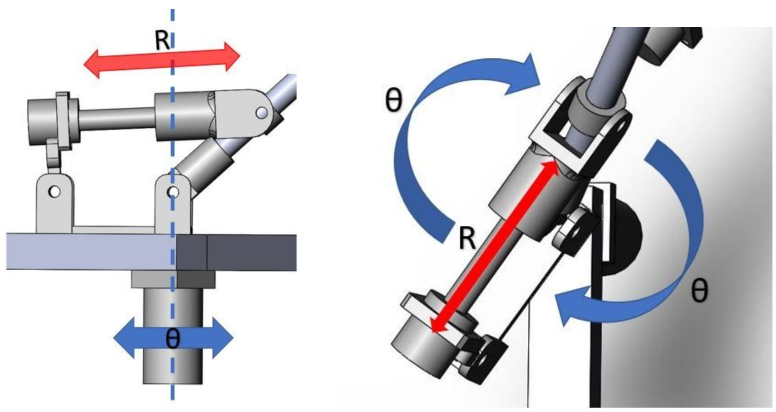


Figure 4. SCOUT hip joint design side view (left) isometric view (right)

At the knee joint, Figure 5, a linear actuator controls the position of the second leg segment in the Φ direction to facilitate complex movement and balance. This, in addition to the hip joint, allows the leg to move with 3 degrees of freedom. Both the hip and knee joints are surrounded in protective coverings made out of silicone to isolate the critical components from abrasive regolith and debris.

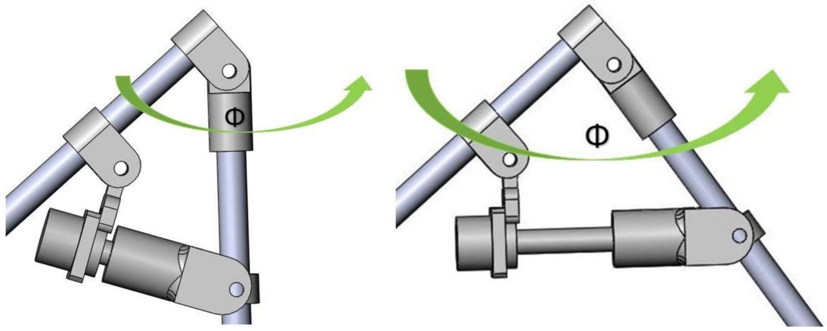


Figure 5. SCOUT knee joint design

4.1.3.2. Foot Design

SCOUT's feet were designed to maximize stability and incorporate features that prevent sinking to be prepared for the uncertainty of terrain and regolith density in PSRs. When an object sinks into the ground, it encounters two resistive forces: side resistance on the sides that enter the ground and an end resistance at the base of the object. While these stress vectors oppose the object entering the ground, they are also displaced horizontally due to the soil arching effect [7]. This effect is caused by the transfer of stress from yielding granular soil to adjacent rigid soil. The results of this effect were capitalized upon while designing the feet. The base X-shape of the feet, as seen in Figure 6 below, has a large perimeter which increases the side resistance and bearing capacity of the feet to prevent sinking. In addition, introducing holes into the X-shape increases the distribution of stress vectors through soil arching [8]. The material elements of the feet were chosen with the purpose of withstanding PSR temperatures and the abrasiveness of lunar regolith. The feet, in addition to the rest of the leg segments, will be made out of a carbon fiber and epoxy composite due to its strength, low mass, and resistance to low temperatures. The soles of the feet, which will sustain the most abrasion, will be constructed out of carbon fiber reinforced nylon with inlaid strands of kevlar.

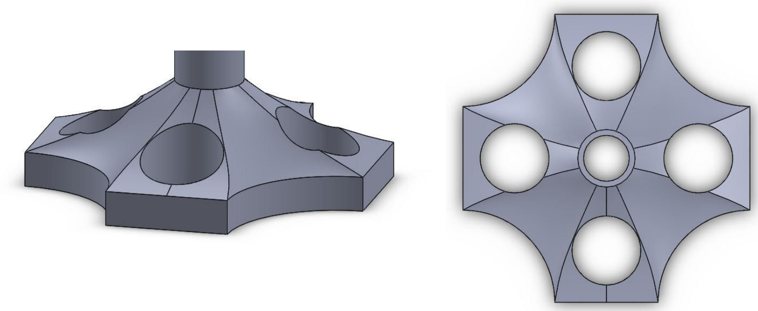
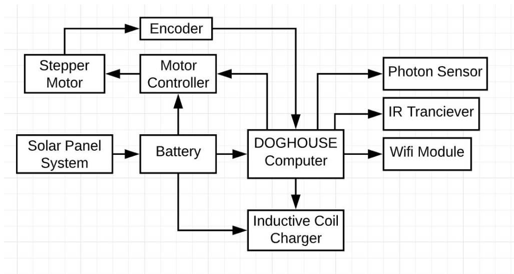


Figure 6. SCOUT foot design isometric view (left), top view (right)

4.1.4. Central Electronics

The central electronics subsystems for both SCOUT and DOGHOUSE will consist of electronics for power storage, allocation, and distribution. The central electronics subsystems will also include space for sensing, data analysis, computation, and communication equipment. The central subsystem for SCOUT includes a charging apparatus for power transfer via inductive coils, an AC-to-DC converter, charge controller, and a lithium-ion battery for power storage. For computing, on SCOUT, a BC-R9 ARM9 Embedded RISC Computer will be used as a master board, with two slave Raspberry Pi boards. One Raspberry Pi will control movement, and one will control navigation. On DOGHOUSE, only a

Raspberry Pi will be used because of the lower computing requirements. Additionally, a circuit will be in place to convert D/C power from the solar panel and battery on DOGHOUSE to A/C for the wireless charging. This will be converted back to D/C on SCOUT, allowing the battery to charge. These circuits will be sourced from the same location as the coils used in this process.



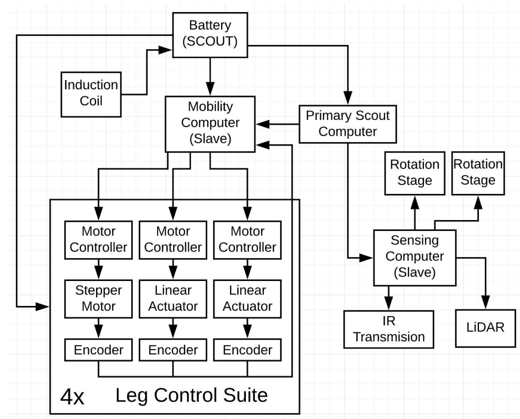


Figure 7. DOGHOUSE Block Diagram (Left), SCOUT Block Diagram (Right)

4.1.4.1. Power Storage and Allocation

In order to choose a battery, the team had to consider the power draw and run time of each of the electronic devices in order to calculate the energy requirements of the vehicle. To properly integrate the power supply and solar panels into the system, charge controllers and DC-DC/AC-DC converters will be incorporated. In order to extract the most amount of power from the solar panels, a Maximum Power Point Tracking algorithm will be implemented. Custom polymer Li-Ion batteries were chosen due to their low mass (1.54 kg), compared to a lithium-ion battery, making SCOUT have more mobility. The polymer Li-Ion battery has a stable overcharge/discharge rate (over-charging beyond 4.25V/cell and Over-discharging below 2.50V/cell) making it difficult for SCOUT to short circuit when being charged by the inductive coil. The battery will be encased in a heavy-duty shrink wrap in order to prevent electrolyte leakage. For the power budget, reference Appendix A.

4.1.5. Communication

Because SCOUT will be operating inside of a PSR, it will not have a direct line of sight to the lander. Rather than transmitting all of the data from SCOUT to the lander over WiFi, data will be transmitted to DOGHOUSE using optical communications systems in the near-infrared range, then to the lander over WiFi. Since DOGHOUSE will be collecting solar energy, power conservation is less of a concern on DOGHOUSE than it is on SCOUT. Communication between DOGHOUSE and SCOUT will use infrared light at a wavelength of 1.3µm, which was selected for cost-effectiveness and power conservation. The 1.3-1.6µm range is often used for fiber optic communications but is equally effective in free space. The infrared transceiver will be constructed from an integrated circuit chip from Maxim Integrated and an infrared LED and photodiode from Marktech Optoelectronics which both operate at 1.3µm. This transceiver system will be implemented on both SCOUT and DOGHOUSE. This computer system can be seen below in Figure 8.

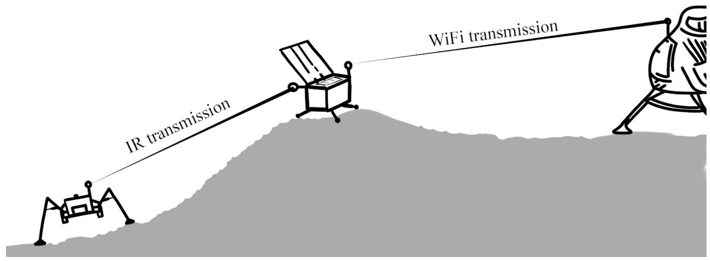


Figure 8. Communication system - IR from SCOUT to DOGHOUSE, WiFi from DOGHOUSE to lander

4.1.6. Navigation

4.1.6.1. SBG Systems

Because of the lack of a GPS system on the moon, SCOUT's position will be recorded using DOGHOUSE as a reference point. To do so, a system that provides acceleration data will be used to calculate the position of SCOUT. This process is successful for short term movement, as would be performed by SCOUT [9]. The choice to purchase a part that performs this function leads to SBG Systems, which specializes in sensing and positioning technologies. After a correspondence was established with the company, SBG systems graciously offered access to off-market technology, allowing for a compact method for measuring the acceleration data. Additionally, to offset the cost SBG Systems offered a full sponsorship of the team, providing the technology at no cost in return for allowing SCOUT and DOGHOUSE to be used in promotional material. The system would be secured through a simple screw mechanism to the main body of SCOUT. Data would then be returned in raw acceleration values though the comms system from SCOUT to DOGHOUSE to the lander and eventually to Earth.

4.1.6.2. Obstacle Avoidance

To allow SCOUT to navigate with minimal human intervention, new innovations have been combined with existing technology. To do this, the first step is to understand the surrounding area by creating a 3D scan of the region. Previous research has been done to prove the capability of LiDAR as a navigation method [10]. Additional research shows success in LiDAR navigation without GPS access [11]. The main obstacle to LiDAR navigation is background light, which is not prevalent within PSRs, making LiDAR navigation an ideal form of map generation. To produce an image, simply purchasing a designated three hundred sixty degrees LiDAR scanner would be prohibitively expensive, so a scanning system was designed.

SCOUT will only need to scan the roughly 180° area in front of it, but the scanner will be able to scan a full 360° in case of a fall or if SCOUT becomes stuck within the PSR. To do this, two points of rotation will be used to adjust the position of the LiDAR sensor during the scan. Because of the size constraints, the chosen system is the LiDAR-Lite v3HP produced by Garmin. Its low mass and small size make this device the ideal commercially available unit for this application. Optical lens positioning rotary platforms were chosen because they are the most compact vacuum ready rotation stage available. Though on Earth the mechanical limit of the devices would present a limiting factor, the reduction in the force of gravity on the moon to roughly ⅙ of that on Earth allows them to function as needed. Carbon fiber was chosen to develop the rotational device supporting the LiDAR scanner because it is lightweight. Additionally, because of the corrosive nature of Lunar Regolith, a polycarbonate cover for the LiDAR scanner would be created. An image of the entire apparatus is shown in Figure 9.

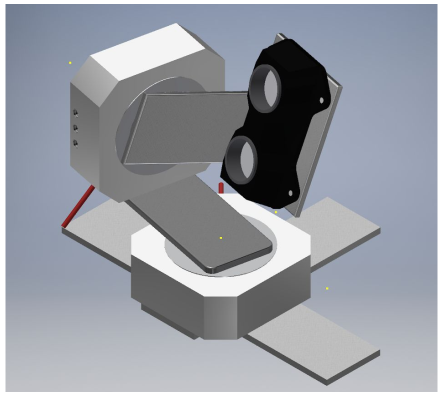


Figure 9. Optical lens positioning rotary platforms enabling movement of LiDAR scanner

Following the LiDAR imaging of the surroundings, SCOUT will process the information and decide the best path to take. Onboard processing allows SCOUT to continue navigating through the PSR in the event that a connection to DOGHOUSE is lost. These scans will be transmitted to DOGHOUSE through a direct connection while charging, then eventually back to the lander via WiFi. This will provide future missions with a more accurate picture of the inside of PSRs.

4.1.7. Data Collection

Throughout the exploration of the PSR, SCOUT will use a LiDAR scanner to generate map data at a maximum range of fifty meters. Using analysis onboard, SCOUT will calculate a path around obstacles within a five-meter range to allow ample time for adjustment. More details on the exact scanning method and the devices used are outlined in the navigation section (4.1.6.2). In order to supplement the data provided by the lander for future automated or manned missions, SCOUT will transmit the contents of each individual scan upon return to DOGHOUSE. This data, though not a replacement for complete visual imaging, will provide information regarding exact positions of large obstacles. The data from the aforementioned SBG systems device will be used to assign positions to each scan. These will be transposed over low orbit pictures of the intended area for exploration, creating a reference guide to the area for future exploration. The individual scans will be transmitted over WiFi from DOGHOUSE to the CLPS lander, which will relay data back to Earth. The position data will be relayed from SCOUT to DOGHOUSE every half meter that SCOUT travels, ensuring that SCOUT's position is always known to a high degree of accuracy.

4.2. DOGHOUSE

4.2.1. Storage Configuration and Deployment

Upon reaching the edge of the PSR, DOGHOUSE will be deployed from beneath SCOUT using the same model HDRM used to deploy SCOUT from the lander. Since it is cost-prohibitive, this component will be omitted from the proof of concept. Instead, bolts will be released by hand during testing. DOGHOUSE's three supporting legs will be made from solid carbon fiber rods. The triangular configuration will provide stability sufficient to keep the solar panel from falling over. The solar panel will initially be folded, as shown in Figure 10, to allow SCOUT's legs to operate in transit to the crater while DOGHOUSE is beneath it.

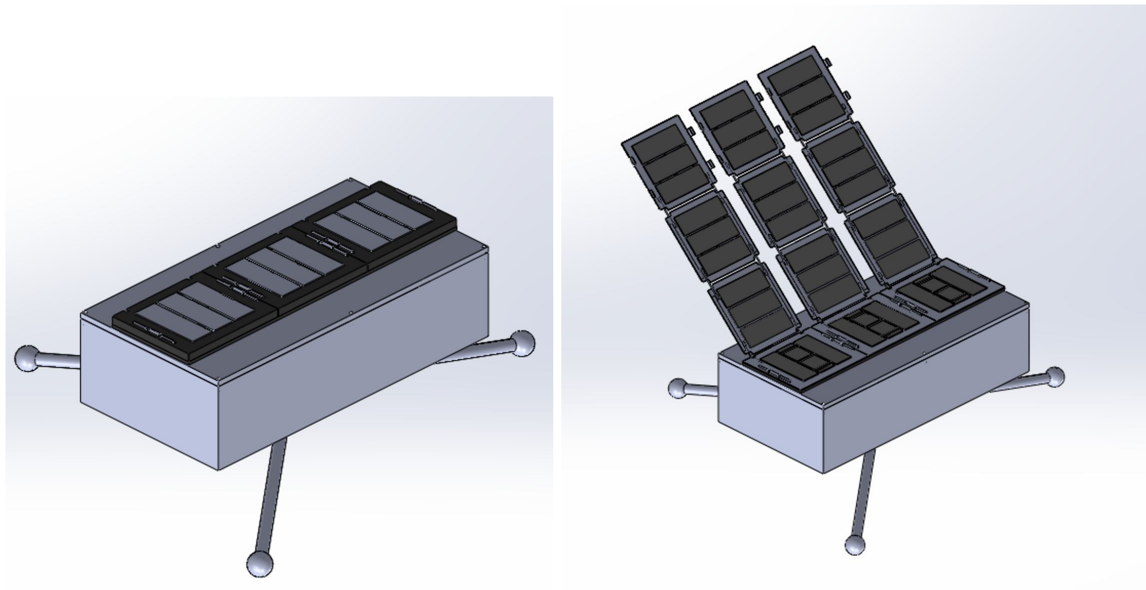


Figure 10. DOGHOUSE in folded and unfolded positions

4.2.2. Solar Panel Design

Ideally, DOGHOUSE would use 3 EXA CubeSat deployable solar panels capable of delivering more than 190W of power to DOGHOUSE's battery. Due to cost restrictions, our proof of concept will use one deployable panel. A secondary panel will be used for testing to supplement the power output, though this would not be included in the final design. Despite this restriction, three panels were included in the mass budget to give an accurate measure of what the final system would weigh. While in transit to the crater, the solar panel will sit flush with the underside of SCOUT. DOGHOUSE's battery will be initially charged so that when DOGHOUSE is released from SCOUT at the edge of the PSR the solar panel will unfold to its operating configuration as shown in Figure 10. There will be an IR receiver above the solar panel to allow DOGHOUSE to communicate with SCOUT during excursions into the crater. DOGHOUSE will be capable of relaying information between SCOUT and the lander using a WiFi transmitter. This will relay signals to establish a connection between the lander and SCOUT, allowing for constant communication.

The solar panel will need to rotate with the Sun in order to efficiently harvest solar energy using a motor placed between the central electronics unit and the base of the solar panel. In order to ensure the solar panel is operating at maximum efficiency, a maximum power point tracking algorithm will be used. The central electronics unit, made of carbon fiber in an aluminum frame, contains a battery used to store solar energy, as well as the necessary computing power to relay communications.

4.2.3. Power Transmission

SCOUT will be using an off-the-shelf wireless inductive coupling coil which delivers electrical energy between two coils within a magnetic field using A/C. This design decision was made with the knowledge that wireless charging is less efficient than wired charging because of the difficulties involved with keeping the charging port dust free. By running A/C current through a coil on DOGHOUSE, the voltage will be induced in an identical coil placed on the rear of SCOUT to charge SCOUT's battery. The coil will transmit power at 200 W with an efficiency as high as 80%. This will allow for expedient charging, maximizing the time SCOUT spends in the PSR.

4.2.4. Communication

On DOGHOUSE, a low power WiFi module from Grid Connect will be installed to allow for the communication of data to the lander. In order for this system to operate in a lunar environment, it would need to be radiation hardened. Because the system is not being tested in a radiation heavy environment, a hardened module will not be used for proof of concept. Because of the maximum 100 m range between the lander and the edge of the PSR, this chip was chosen as the range exceeds this requirement.

4.3. Concept of Operations

SCOUT and DOGHOUSE will be fabricated largely out of fiber composite material. Most of the structural components will be constructed using traditional techniques, the robot's Kevlar feet will be 3D printed. The remainder will utilize off-the-shelf components. Assembly and testing will be done by hand, then SCOUT will be launched on a CLPS lander. The lander will deliver SCOUT to the lunar surface within 100 m of a permanently shadowed region at the moon's south pole and should land at the beginning of a lunar day in the region. Upon arrival, SCOUT will deploy from the lander and begin operation on the lunar surface. SCOUT will begin its mission with enough battery power to make the trip to the edge of the PSR. At this point, it will deploy DOGHOUSE onto the lunar surface. DOGHOUSE will unfold a solar panel and communications equipment to serve as a home base for SCOUT's mission. With DOGHOUSE deployed, SCOUT will then progress the PSR.

Inside of the PSR, SCOUT will begin collecting data using appropriate stand-alone sensing systems. These may include cone penetrometers, thermometers, or cameras. These have not been included in this design; SCOUT is meant to be a transportation system for any sensing equipment needed for future missions. DOGHOUSE will be a reference point to make a position map of its data points and will include an IR transceiver and WiFi chip to transmit data from SCOUT to the lander. DOGHOUSE will continually gather solar power while SCOUT is in the crater. The rover will return to recharge when its battery reaches 55% so that it does not get trapped in the PSR. As the mission lifecycle ends, SCOUT will remain in the crater to gather as much data as possible. The mission will end when the lander can no longer transmit data back to Earth. Since the lander is not designed to survive a lunar night, SCOUT and DOGHOUSE will cease operation and remain dormant on the lunar surface.

4.4. Path to Flight

SCOUT and DOGHOUSE will not be tested for space compliance because of the added cost of acquiring space-rated components. Quotes for a number of space-rated components were found, including batteries, steppers, actuators, a computer, and rotation stages. Using these space-rated components would cost about $150,000, which would put the project out of budget when added to everything else that goes into this prototype. At this point, the decision was made to forgo space-rating SCOUT and DOGHOUSE, and instead only test with Earth specifications. Therefore, in order to make SCOUT and DOGHOUSE space ready, their parts need to be replaced with space-compliant versions and they would need to be tested in a vacuum and cryo environment. Electronic components would also need to be radiation hardened to function properly in a space environment.

4.5. Testing

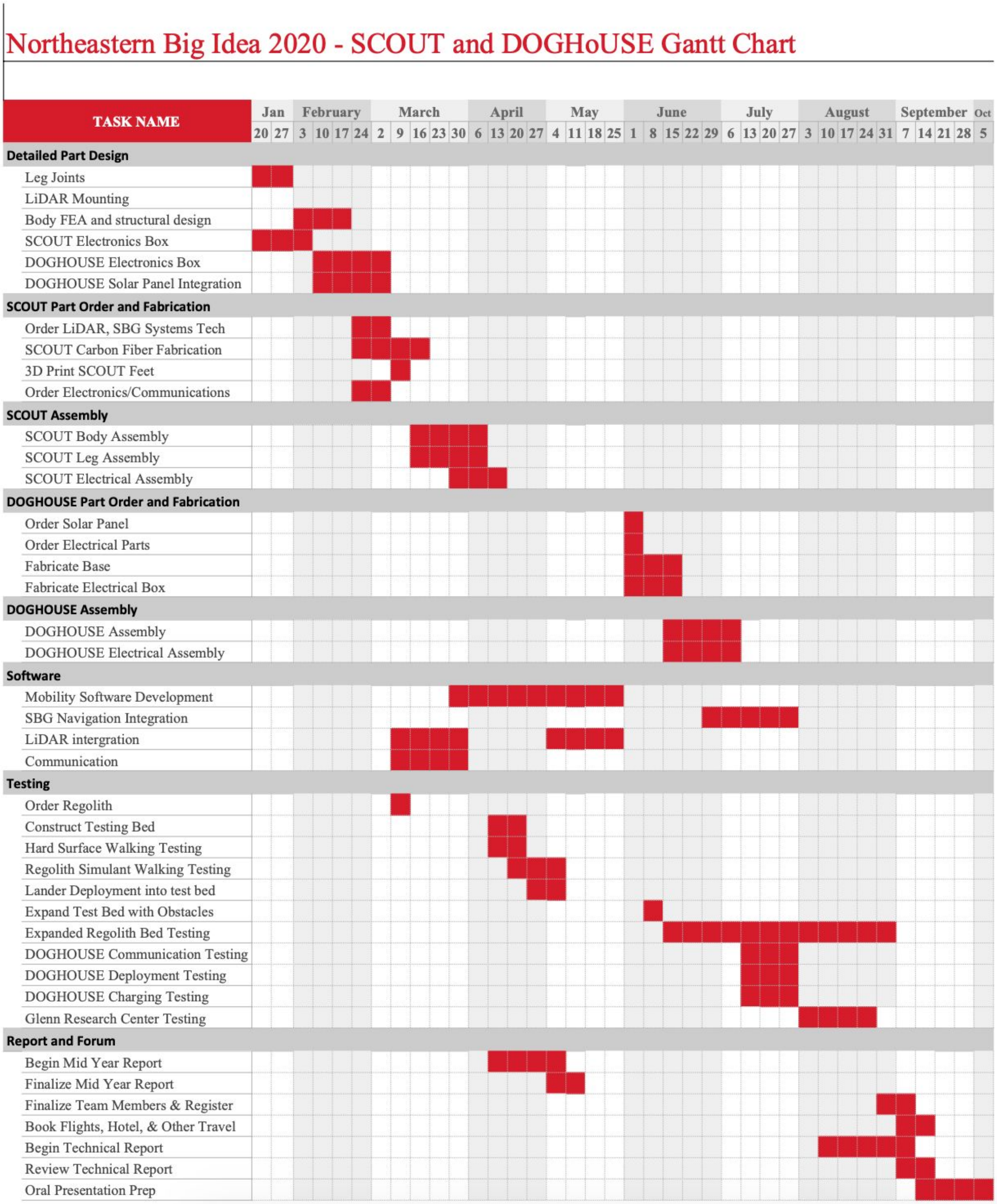
SCOUT will be placed in a simulated lunar environment composed of the regolith simulant LHS-1, as designed by the Exolith Lab at the University of Central Florida. The regolith will be laid 8 in deep in a 6 ft by 6 ft square. The simulated environment will also include obstacles such as rocks, divots, and other types of uneven terrain around which SCOUT will navigate. This will demonstrate the robot's ability to choose a path between a destination and return to the starting point while avoiding obstacles. SCOUT will also be required to return to its starting point in order to simulate a return to DOGHOUSE for charging. SCOUT will be evaluated on its ability to make movement decisions and act in a timely manner. DOGHOUSE's release sequence will also be tested in this environment. SCOUT will drop DOGHOUSE into the simulated regolith, then step away to allow DOGHOUSE to set its legs using the spring-loaded release mechanism and begin solar panel operation. In addition to navigation in the level regolith environment, SCOUT's ability to maneuver down a slope with a maximum incline of 15° will be tested. It will be evaluated on its ability to stay level and adapt to the changing slope as it enters and exits the crater.

SCOUT and DOGHOUSE will be dropped from a height of 0.8 m to simulate the maximum forces they will experience on the moon. Understanding that the force of gravity on the moon is approximately one-sixth of Earth's, the system will experience a maximum of 26 N of impact force during deployment. Thus, by dropping the unit from this overestimated height, we believe that this will ensure the SCOUT's successful deployment. This test will also ensure the effectiveness of the SCOUT's release mechanism. To do this, a model of the lander's release mechanism, as described in the Example Payload User Guide, will be built and the release will be tested to ensure that the SCOUT-DOGHOUSE unit will be released safely and effectively.

In order to test DOGHOUSE's ability to relay data between SCOUT and the lander, a receiver similar to that on the lander will be placed outside of the line of sight with SCOUT. DOGHOUSE will be placed such that it has a line of sight with both SCOUT and the lander. Test communications at 70 kbps/kg will be sent from SCOUT to DOGHOUSE using IR, and that data will be relayed to our mock lander using WiFi. Ideally, the lander will be placed no less than 100 m from DOGHOUSE, and SCOUT another 50 m away from DOGHOUSE. The difference in atmosphere between the Earth and moon should have little effect on the proof of concept obtained from this test.

We are also prepared to test our system to ensure compliance with the MIL-STD-461D standards CE102, CS101, CS114, CS115, and CS116, as specified in Astrobotic's Payload user guide if the cost for these additional testing services is determined necessary by the judges' panel. Finally, we intend to finalize our testing at the Johnson Space Center's Vibration and Acoustics Testing Facility (VATF). Specifically, we would conduct shock testing at the General Vibration Laboratory (GVL). Completing this testing would allow us to ensure that our system's design will withstand the shock experienced during launch sequences. Thus, through these two forms of external testing, we will ensure that our system is fully compliant with the minimum CLPS payload requirements.

5. TIMELINE


Northeastern Big Idea 2020 - SCOUT and DOGHoUSE Gantt Chart
TASK NAME
Jan
February
March
April
May
June
July
August
September
Oct
20 27 3 10 17 24 2 9 16 23 30 6 13 20 27 4 11 18 25 1 8 15 22 29 6 13 20 27 3 10 17 24 31 7 14 21 28 5
Detailed Part Design
Leg Joints
LiDAR Mounting
Body FEA and structural design
SCOUT Electronics Box
DOGHOUSE Electronics Box
DOGHOUSE Solar Panel Integration
SCOUT Part Order and Fabrication
Order LiDAR, SBG Systems Tech
SCOUT Carbon Fiber Fabrication
3D Print SCOUT Feet
Order Electronics/Communications
SCOUT Assembly
SCOUT Body Assembly
SCOUT Leg Assembly
SCOUT Electrical Assembly
DOGHOUSE Part Order and Fabrication
Order Solar Panel
Order Electrical Parts
Fabricate Base
Fabricate Electrical Box
DOGHOUSE Assembly
DOGHOUSE Assembly
DOGHOUSE Electrical Assembly
Software
Mobility Software Development
SBG Navigation Integration
LiDAR intergration
Communication
Testing
Order Regolith
Construct Testing Bed
Hard Surface Walking Testing
Regolith Simulant Walking Testing
Lander Deployment into test bed
Expand Test Bed with Obstacles
Expanded Regolith Bed Testing
DOGHOUSE Communication Testing
DOGHOUSE Deployment Testing
DOGHOUSE Charging Testing
Glenn Research Center Testing
Report and Forum
Begin Mid Year Report
Finalize Mid Year Report
Finalize Team Members & Register
Book Flights, Hotel, & Other Travel
Begin Technical Report
Review Technical Report
Oral Presentation Prep

6. BUDGET

In order to build a prototype of SCOUT and DOGHOUSE, a budget totaling $90,889 is being proposed. This total can be split into the following portions: DOGHOUSE, mobility system, body, electrical, navigation, communication, and lander interface. Since the mobility system is the largest concern and the point of greatest innovation, this has the largest budgetary requirement at $33,130. Specifically, the actuators are high cost because there are many of them and they need to be high quality to minimize the chance of mechanical failure. DOGHOUSE is also a significant part of the budget, totaling $23,697. In order to fit the small form factor beneath SCOUT and provide sufficient power for the system, a deployable, powerful solar panel was needed. The cost of the Stepper DC motors, totaling $6,870, is due to the required encoders, gearboxes and torque requirements for the system.

To travel from Boston to Houston for the final competition, travel by plane was most optimal. The cost of $6,600 reflects airfare for twelve students to attend the event, as well as our advisor. Additionally, rental cars for movement around Houston and transit to the airport.

Figure 11: Budget Chart

SCOUT and DOGHoUSE at a Glance		Tools and Testing		Travel	
Mobility System	$33,130	Hand Tools	$20	Airfare	$6,600
DOGHOUSE	$23,697	Power Tools	$50	Hotel Rooms	$1,800
Electrical	$3,350	Enviornment Materials	$230	Rental Cars	$800
Navigation	$2,573	Regolith	$1,303	System Transport	$90
Communication	$386	Travel to JSC	$360	Registration	$3,600
Lander Interface	$300	Outside Testing	$12,600		
Total	$63,436	Total	$14,563	Total	$12,890
Grand Total			$90,889		
Total w/out outside testing:			$78,289		

Mobility System Breakdown		DOGHOUSE Breakdown		Navigation Breakdown	
Leg Tubing	$40	Materials	$400	SBG Systems Gemsis Device	$3,800
Actuators	$22,520	Solar Panel and Deployment	$19,400	LiDAR Lite v3HP	$149
Joints	$950	Non-Space Panel	$1,000	Motorized Rotation Stage x2	$2,404
Steppers/DC	$6,870	Electrical	$800	PLA Plastic	$20
Fabrication/Material	$2,750	Fabrication Cost	$2,000	SBG Systems Sponsorship	-$3,800.00
Feet Material		Secondary Computing	$70.00		
		IR Reflector	$27		
Total	$33,130	Total	$23,697	Total	2573

Lander Interface Breakdown		Communications Breakdown		Electrical Breakdown	
Pulleys	$150	MTPD1346D-150 x5	$157	Motor Controllers	$150.00
Cable	$20	MTE1300NN1-WRC x5	$167	DOGHOUSE Battery	$400
Gripple Rope Clamps	$30	MAX3120ESA+ x5	$22	Computers	$1,400
Vibration Dampeners	$100	IR housing - PLA	$20	Motor Controller - Act.	$550
		Wifi Chip	$20	Motor Controll - Stepp.	$350
				SCOUT Battery Charger	$100.00
				SCOUT Battery	$400.00
Total	$300	Total	$386	Total	$3,350.00

This total budget includes optional testing through National Technical Systems (NTS) which will ensure our system is fully compliant with the MIL-STD-461D standards as specified in Astrobotic's Payload user guide. If this additional testing is not deemed necessary, this section of the testing cost, totaling $12,600, can be eliminated. This would put us at a smaller total cost of $78,289. Additionally, the final mass of the SCOUT and DOGHOUSE system totals to 13.137 kg. Major mass expenditures are the two batteries, totaling 1.360 kg each for DOGHOUSE and SCOUT, the DC motors for SCOUT at 4.280 kg, and the SCOUT actuators at 1.088 kg.

7. CAPABILITIES STATEMENT

Core Competencies

SCOUT is a team of 13 undergraduate students at Northeastern University. We are a subset of Northeastern's chapter of the Students for the Exploration and Development of Space. Our team has members in a variety of areas of studies, including mechanical, electrical, and computer engineering, computer science, and physics. By having members across these disciplines, our team has the analytical and design capabilities necessary to complete every aspect of our project. One of our team members has professional experience designing and analyzing metallic components for applications in high vibration and thermal environments as an intern for SpaceX working on the crew dragon system.

In addition to the experience of individual SCOUT members, our team also has important outside support from our advisors. Dr. Alireza Ramezani, a mechanical and computer engineering professor at Northeastern, researches, and constructs quadrupedal robots. His experience in this area is directly relevant to the fabrication and testing of 4-legged rovers. We also have the support of Dr. Taskin Padir, an electrical and computer engineering professor at Northeastern, who has advised SEDS Northeastern since its creation. He runs the RIVeR laboratory and has experience with humanoid robots. From both of these professors' experience, our team has the support we need to move forward with this project.

Facilities and Equipment

As a club, Northeastern SEDS has access to a professional workspace with tools for mechanical and electrical fabrication. The SCOUT team will be allocated space from this workspace to manufacture and test our system. The team will also have access to fabrication equipment from Northeastern University. These resources will include a fully equipped CNC machine shop and a high-quality 3D printer capable of printing in fiber composite materials.

Differentiators

One of the most important differentiators of our team is the wider support network we have access to. Beyond our 13 member team, the SCOUT team is surrounded by Northeastern SEDS, which is made up of over 200 students on other space projects. We can seek support not only from our advisors but also from this support larger network to ensure success. Our team has already seen the benefits of being able to reach out to this wider network, and this will continue to be instrumental in our success going forward.

Past Performance

Members of SCOUT also have experience in numerous past projects, including RASC-AL, Mars Rover, Mars Ice, and Hyperloop. Participating in these other competitions has given us experience working in this type of environment, with all the necessary technical and project management skills. Our wider club has had substantial success in past competitions, including being a RASC-AL Classic Finalist Team in 2019; being the only first-year team to chosen attend the final University Mars Rover Challenge competition at the Mars Desert Research Station in Hanksville, Utah; achieving first place in Mars Ice in 2018; and tying for best technical paper for Mars Ice in 2019.

Appendix A: Power Budget

POWER BUDGET	Power (watts)
PANEL INPUT	**200.00**
DOGHOUSE Electronics Element	
stepper motor	9.60
motor controller	0.83
WiFi Output	0.83
Raspberry Pi	15.00
IR Transceiver System	0.58
TOTAL DOGHOUSE POWER USED	**26.84**
Inductive Coil Charger Efficiency	0.80
CHARGE INPUT FOR SCOUT	**160.00**
SCOUT Electronics Element	
Arm9 Embedded RISC Computer	10.00
Raspberry Pi X 2	30.00
IR Transceiver	0.58
GEMSYS SPG System	1.00
LIDAR	0.43
Motor Controller	0.83
Linear Actuator Controller	0.83
Stepper X 4, Linear Actuator X 8, Rotation Stages X 2	100.00
TOTAL SCOUT POWER USED	**143.67**

Appendix B: References

[1] Paige, David A., et al. “Diviner Lunar Radiometer Observations of Cold Traps in the Moon's South Polar Region.” Science, American Association for the Advancement of Science, 22 Oct. 2010

[2] Soil Science Society of America. "NASA’s Dirty Secret: Moon Dust." ScienceDaily. *ScienceDaily*, 29 September 2008.

[3] Dunbar, Brian. “The Moon and the Magnetotail.” *NASA*, NASA, 16 Apr. 2008.

[4] Henriksen, Megan. “Lunar Reconnaissance Orbiter Camera.” LROC, 27 Jan. 2018.

[5] Retherford , Kurt. “Seeing in the Dark: Exposing the Moon's Permanently Shadowed Craters.” SPIE, The International Society for Optics and Phonics, 16 Apr. 2012.

[6] “Peregrine Lunar Lander.” *Payload User’s Guide*, v. 3.3. Astrobotic, 2017.

[7] Kempfert, Hans-Georg, and Marc Raithel. “Arching Effect.” *Arching Effect - an Overview | ScienceDirect Topics*, Science Direct, 2015.

[8] He, Gang, et al. “Soil Arching Effect Analysis and Structure Optimization of a Robot Foot Sinking in Soft Soil.” *Advances in Mechanical Engineering*, vol. 9, no. 8, 23 Aug. 2017.

[9] Liu, H.h.s., and G.k.h. Pang. “Accelerometer for Mobile Robot Positioning.” *IEEE Transactions on Industry Applications*, vol. 37, no. 3, May 2001.

[10] Hiremath, Santosh A., et al. “Laser Range Finder Model for Autonomous Navigation of a Robot in a Maize Field Using a Particle Filter.” *Computers and Electronics in Agriculture*, vol. 100, Jan. 2014

[11] Liu, Shifei, et al. “A LiDAR-Aided Indoor Navigation System for UGVs.” *Journal of Navigation*, vol. 68, no. 2, 2014.