Preliminary Design Concept of Locust Inspired Jumping Moon Robot Swarm. B. K. Herkenhoff[1], S. Lanctot[1], J. M. Fisher[1], N. Serda[1], T. S. Bjorkman[1], V. Martinez[2], T. Johnsonand[2], C. Davis[2], T. Yazzie[2], N. Vadiee[3], M. Hassanalian[4]. [1]Undergraduate Student, Department of Mechanical Engineering, New Mexico Tech, Socorro, NM 87801, USA, [2]Undergraduate Student, Department of Engineering, Southwestern Indian Polytechnic Institute, Albuquerque, NM 87124, USA, [3]Professor, Department of Engineering, Southwestern Indian Polytechnic Institute, Albuquerque, NM 87124, USA, [4]Assistant Professor, Department of Mechanical Engineering, New Mexico Tech, Socorro, NM 87801, USA.

Introduction: As it stands, the two primary focuses of space exploration are the Moon and Mars, due to the attainable travel distances using current technology. Both provide a unique challenge in exploration and data collection; however, as the Moon has no atmosphere, the modern approach of aerial drone-based exploration is not an option. In the past, planetary exploration and data collection has been limited by the employed modes of transportation in related missions. The main implementation has relied on more traditional automobile-based rovers; however, this method is significantly limited by maneuverability. Unfortunately, rough terrain, obstacles, dust storms, and environmental conditions make it challenging for traditional land rovers to efficiently explore and cover large amounts of terrain. Applying these land rovers has opened many exploration and data collection opportunities, but the rate at which these have been carried out leaves more to be desired, especially due to the large number of unreachable areas.

Considering this, the implementation of a novel bioinspired design focused on the jumping locomotion of locusts may be advantageous as such a design could reduce the limitations of exploration by vastly expanding the movement capabilities of rover systems on the Moon. In conjunction with this expanded range of movement, this design would be compact and lightweight allowing for the transportation of several units designed to operate in a swarming fashion. These swarm mechanics would allow for communication between members to more effectively perform missions over a large area, such as terrain mapping, or lava tube exploration.

Figure 1:Locust-inspired robot for lunar surface exploration.

Locusts were selected as the primary inspiration due to their noteworthy control when performing movements, providing high maneuverability, and their capability to effectively jump much higher and farther than their size. This capability would allow for the exploration of hard-to-reach areas such as elevated regions, steep slopes, and highly rocky obstructed terrain. The implementation of a swarm of the suggested robot will allow for continuous data collection with the ability to easily reach previously challenging areas with higher efficiency. The swarm aspect of this design will allow for a significant number of data points to be collected at a high rate while providing backup units in the event of a failure or malfunction, ensuring extended survival of the mission [1-4].

The swarm of the proposed bioinspired concept: (1) has significant merit and enables dispersed measurements at different cave and lava tube locations on Moon; (2) has the capability to obtain thermal information, temperature, radiation levels, and geothermal heat sources; (3) to obtain images of walls, ceiling structures, and floors in the caves and lava tubes; (4) obtain information and images of any water sources, and subterranean aquifers. A very crude and early representation of these design intents can be seen in Figs. 1 & 2. It would utilize two main jumping legs connected to a central body that will house necessary electronics and actuation mechanisms. This housing will also provide a platform for exterior solar panel mounting as a common energy harvesting technique. By employing the key jumping mechanisms of a locust, an effective transportation mode will be attained, allowing for increased efficiency and range of traversable terrain, resulting in greater opportunity for data collection. Some of the critical criteria being considered for this design include the ability to dynamically control the jump vector, allowing a high degree of precision motion along with the selection of landing locations based on the terrain ahead. The methods for how this control will be achieved are part of future design challenges. Due to the instability in regard to jumping and landing, this design will require self-correcting capabilities to operate from any position to ensure successful function.

Figure 2: Proposed robot for lava tube exploration.

The Artemis Mission: The versatility of movement that the Lunar Locusts are equipped with due to the jumping mechanism allows for the swarm robots to be applied in multiple locations on the lunar surface. Furthermore, the Lunar Locusts will be able to complete a multitude of different tasks on the lunar surface including but not limited to surveying and exploring the lunar surface and lunar lava tubes. These tubes, potentially being unsafe for astronauts to explore due to stability issues, could shield astronauts from radiation for greater lunar expansion. In addition, the exploration of lunar lava tubes can prove the hypothesis that ice has been formed under the lunar crust.

To ensure the success of NASA's Artemis mission, the Artemis team must have enough information to complete the mission objectives. Before and after manned missions to the Moon, information about the lunar surface is vital to scout proper landing, architectural, and geological sites. The mechanics and size of the Lunar Locust robot would give it the ability to explore areas with rough terrain and where traditional locomotion is ineffective. To complete this goal, the Lunar Reconnaissance Orbiter satellite is planned to provide surface data on the lunar environment where the Artemis III mission is set to land. In conjunction with this orbital satellite, the Lunar Locusts will be beneficial in characterizing and documenting the lunar geology on the Moon's south pole.

Lunar regolith has extremely harmful effects on lunar equipment, as there are four planned EVAs for the Artemis III mission. The use of the Lunar Locusts to survey and prepare for the EVAs will limit the abrasive effects of the moon dust on the integral life support equipment the astronauts will be using. Furthermore, by using a swarm of semi-autonomous drones to explore the lunar environment, the astronauts will be well equipped with intimate knowledge of the environment they will be venturing into. This in turn means the astronauts will be more prepared and safer in the hazardous lunar environment [1-4].

Lunar Locust Design: Before locusts jump, they have a "super crouch" position where they can store increased amounts of energy to be released upon the jump, which can be seen in Fig. 3(B).

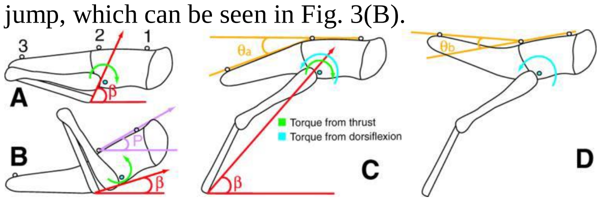

Figure 3: Grass locust jumping mechanism [2].

Researchers at UC Berkeley have developed the SALTO robot, which has similar inspirations and contains noteworthy design elements that will be beneficial to the leg construction in a locust inspired jumping mechanism (see Fig. 4). In the development of this robot, a comparison of different common jumping techniques was performed to ascertain what system is the most effective, both in terms of height and frequency. From this research, it was determined series-elastic systems, in conjunction with a mechanical advantage, can perform the best. A series-elastic robot places a spring element between a rigid actuator and the environment, accomplishing the following: reducing the impedance of the jumping appendage, safeguards a potentially fragile actuator, allows force controllability and passive energy recovery, and enables power modulation without coupling leg position to energetic state [5].

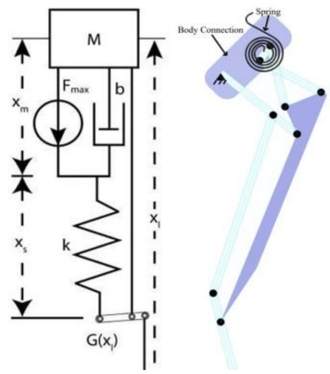

Figure 4: Jumping mechanism.

By using such a system, the jumping robots will be capable of significant jumping height and frequency while conserving energy through stored potential. In addition to this, the implementation of an elastic system also reduces the shock from landing, reducing the risk of wear over extended use. Choosing a lightweight and strong leg material is critical to have a successful model because it is essential as the legs' lengths significantly contribute to the moment of inertia of the robot.

The legs' design on the proposed robot will closely mirror the design seen in Fig. 4. This design makes use of two stiff members in the upper leg, with a lower more flexible member attached. This design adds additional damping to the system providing softer landings and storing a small portion of the energy released in the jump. The conceptual leg also relies on a torsion spring (potentially an elastic polymer), which sits on the leg's pivot point to implement the series elastic system, allowing for increased storage of energy before the jump. These mechanisms, in combination with the mechanical advantage of the design, will allow for greater jumping capabilities and reduced energy expenditure.

References:

[1] Sherman, M. et al. (2020) *AIAA Aviation Forum 2020*. [2] Zhang, C. et al. (2020) *Robots and Autonomous Systems*. [3] Ribak, G. (2020) *Current Opinion in Insect Science*. [4] Lunar Exploration Program Overview. (2020) *NASA*. [5] Haldane, D. W. et al. (2016) *Science Robotics*. [6] Chen, K. et al. (2016) *International Journal of Advanced Robotic Systems*.