Bioinspired Walking, Rolling, and Jumping Robot for Venus Exploration. A. Western[1], M. Hassanalian[2], [1]Graduate student, Department of Mechanical Engineering, New Mexico Tech, Socorro, NM 87801, USA, [2]Assistant Professor, Department of Mechanical Engineering, New Mexico Tech, Socorro, NM 87801, USA.

Introduction: The environmental conditions on Venus are extremely harsh and have led to the quick destruction of many landers. The atmosphere temperature on the surface can reach over 700 K, and is composed of 96.5 % carbon dioxide and 3.5% nitrogen with clouds of sulfuric acid. Temperatures that high can melt metals with lower melting points after only a few hours of being on the planet's surface. The atmospheric pressure on Venus is 93 bar, over 90 times that of Earth's, which can lead to unforeseen consequences if not carefully planned for. The surface of Venus is covered in volcanoes, rocky plains, and mountain ranges, with peaks reaching 7 miles in height. Research suggests that Venus is volcanically active and has had several large eruptions over the past few decades.

Venera 13 lasted the longest out of all landers that have reached the surface of Venus. It transmitted data for over 2 hours before failing. Pictures transmitted showed a relatively flat surface covered in sediment and slabs of rock. Ground samples determined the surface material corresponded to volcanic rock. Developing a small robotic system for the exploration of Venus that is capable of walking, running, rolling, and jumping would allow for quick and efficient movement across Venus' rocky surface [1].

Inspiration from Organic Creatures: Earth's organisms have evolved to be efficient and resourceful in a wide variety of environments. They have adapted and developed unique skills to give them an advantage over other creatures. Nature is full of inspiration for designs, and mimicking natural characteristics can provide for a more successful design. The pressure on Venus is comparable to the pressure roughly 950 m below the ocean's surface. The ocean's Bathypelagic zone starts at 1,000 m below the surface and extends to 3,900 m below the surface. The zone below the Bathypelagic zone is the Abyssopelagic zone, which extends down to around 6000 m below the surface. Deep-sea creatures that live in the Abyssopelagic zone survive in pressures reaching 760 bars. Empty cavities in their bodies have evolved to be minimized in volume to protect against collapsing. In Fig. 1, some examples of these creatures are shown.

Fig. 1. Views of natural creatures underwater.

Proposed Bioinspired Robot: The proposed robot in this study will draw inspiration from three different animals, including the Long-nosed Leopard lizard, Golden wheel spider, and Octopus. The Long-nosed Leopard lizard lives in flat, wide-open deserts with sparse vegetation, such as the Mojave desert. The wide-open spaces allow for prolonged running and basking. The lizard's coloration changes seasonally between darker and lighter shades of brown. The longer limbs allow the lizard to hold itself higher above the surface, which results in less absorption of radiating surface heat. When running quickly, it runs on its hind legs while holding its front limbs up in the air. Toes with small spiny scales allow for the lizard to run across the sand without sinking. In Fig. 2(a), a view of this spider is shown.

The Golden wheel spider moves in a very unique way (see Fig. 2(b)). In order to conserve energy, the spider spreads its legs out around it's body in a circle and rolls down a sloped surface. The longer the spider is able to roll, the more momentum it gains. This effortless motion allows the spider to move quickly to escape predators without expending its energy.

Octopus can move across the ocean floor by walking on their tentacles (see Fig. 2(c)). They have no skeletons, but their bodies are very muscular and supported by fluids. They have two tentacles that are especially muscular and can support their bodies as they walk underwater. Octopuses are also capable of crawling onto land and moving out of the water for extended periods. The suckers on the undersides of their tentacles allow for climbing up vertical surfaces. They have also been sighted rolling across the ocean floor, sometimes inside of objects, such as coconut shells, pushing themselves with their tentacles. Rolling inside of a shell allows the octopuses to move quicker, as well as protection from any predator.

Fig. 2. Views of (a) walking Long-nosed Leopard lizard, (b) rolling Golden wheel spider, and (c) rolling Octopus.

The proposed robot would mimic aspects of all three animals to move across the sediment covered surface of Venus rapidly. The robot's body will be spherical with multiple legs that can change configuration around the body. Like the Long-nosed Leopard lizard, these legs will have wide, flat feet to increase surface area and allow for traction on the sediment. Longer legs will be able to help slightly protect the robot from surface radiation. The robot will be able to walk/run when the legs are positioned on one side. The robot will roll by placing the legs in a ring configuration around the body, similar to the Golden wheel spider. Rolling will be useful when going down slopes to save energy and will allow for quick movement. Rolling on flat surfaces still allows for efficient movement due to the momentum gained. Like the octopus, the robot will be able to boost its rolling on level surfaces with quick, small movements from the feet. The robot will be able to bend the legs and jump while rolling. The robot will be made of flexible composite capable of withstanding the high temperatures on Venus' surface. The electronics will be housed inside of the spherical body. Equal distribution of weight inside of and around the robot will help to balance it while rolling. In Fig. 3, views of the proposed robot are shown.

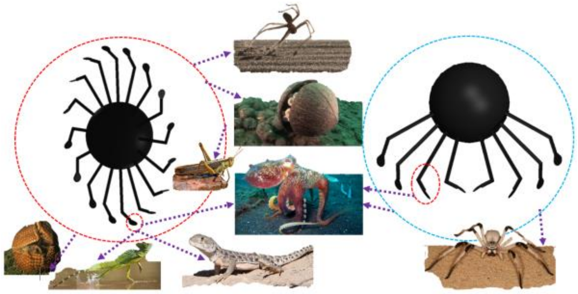

Fig. 3. View of proposed bioinspired walking, rolling and jumping transformer robot for Venus exploration.

The creation of a small, mobile robot allows for the exploration of a larger area of Venus' surface than the traditional landers. Landers are limited to exploring the area around the landing site and are confined to suitable terrain. The robot's ability to walk, roll and jump will allow for the exploration of a wider variety of terrain, such as mountains, with increased speeds. The use of cameras would allow for high-resolution imaging around the robot, providing detailed pictures of a larger range of Venus' surface. Images taken from the surface will provide a clear view of the topography. Orbiters are capable of geographical mapping over large distances, but the resolution is limited. While the surface robot would not be able to map as large of an area as an orbiter, it will be able to provide much more detail [2].

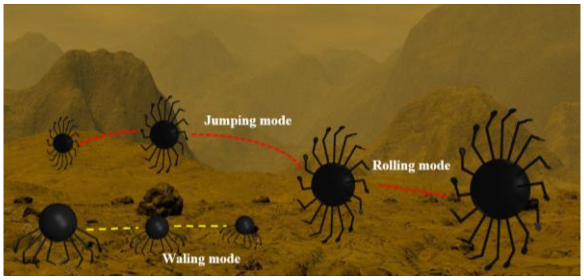

Fig. 4. View of the proposed robot on Venus' surface.

Modeling of the Bionsoired Robot: In Fig. 5, W is the weight of bioinspired robot, R is the radius of the sphere, M_c is the moment about the center of the sphere, M is the mass of rover, g is the gravity on Venus (8.87 m/s^2), N is the normal force, F_f is the force of friction, μ is the coefficient of friction, F_D is the drag force, C_D is the drag coefficient, A is the reference area, ρ is the density of the atmosphere on Venus surface, and V is the velocity pf the robot [3].

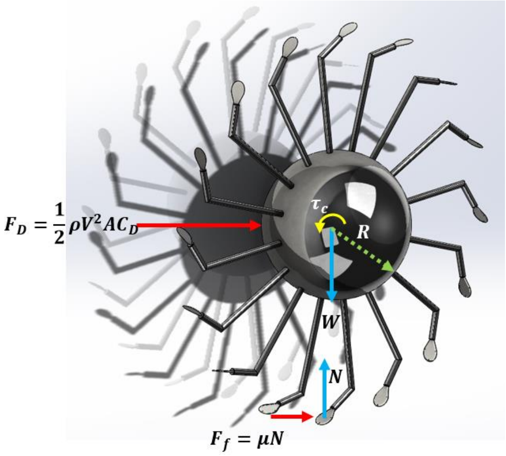

Fig.5. Schematic of forces acting on Venus robot.

As shown in Fig. 6, the robot is modeled as two rigid body systems.

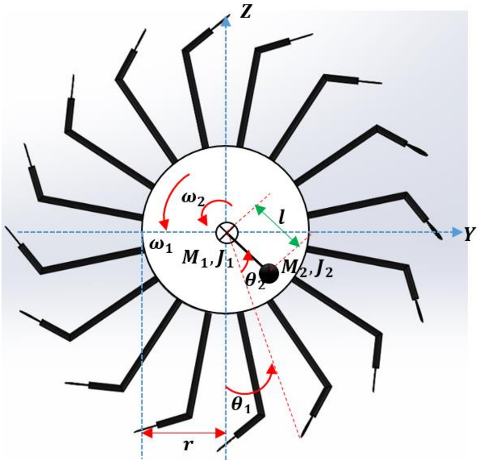

Fig. 6. Dynamical modeling of the driving system.

Applying Lagrange equations, we have:

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \omega_1}\right) - \frac{\partial L}{\partial \theta_1} = -T \tag{1}$$

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \omega_2}\right) - \frac{\partial L}{\partial \theta_2} = T \tag{2}$$

where T and t are the torque between the sphere and the pendulum and time, respectively.

References:

[1] Aguirre A. A. G. (2020) *AIAA.* [2] Hassanalian M. (2018) *Progress in Aerospace Science*. [3] Landa K., Pilat A.K. (2015) *IEEE.*