General Information about the Martian Landscape

Mars’s terrain is geologically diverse, containing features such as rugged highlands, smooth lowlands, cratered plains cones, troughs, ridges, impact craters, etc. (Zhao et al., 2021). Dust storms caused by strong winds are also very common, picking up fine Martian dust and particles. The Martian soil is primarily composed of fine particles of iron-rich volcanic rock, giving the planet its signature reddish color due to iron oxide. Its soil consists of silicates, sulfates, perchlorates, and some traces of salt. The gravity of this planet is around 38% of Earth’s, making the regolith loose and fluffy, reducing particle compaction and surface cohesion. Common obstacles for these rovers include sand traps, slopes, rocks, and sand dunes. The combination of a diverse, rocky terrain with soft sand makes it easy for the wheels of a planetary rover to get damaged and/or sink into the Martian soil.

Rover Mobility and Mechanical Design

Mobility is essential to the success of planetary rover missions, allowing the rovers to navigate to different parts of the planet for in-situ observation. Getting stuck in the Martian terrain can lead to the end of a rover’s mission. These embedding events are caused when the rover experiences significant amounts of sinkage and slippage. Sinkage is defined as the degree to which a wheel sinks into soft soil, and slippage is defined as the difference between the distance the rover wheels were supposed to travel and the actual distance it moved. Traction is another key property needed by rovers, as it allows them to grip onto a surface and propel itself forward; however, it can also cause an increase in the slippage of a vehicle on loose terrain (Girija et al., 2023). This effect can be reduced by increasing the rover’s contact area with the surface, by either increasing the width of the vehicle’s wheels (Hu et al., 2024) or by making the wheels conform to the surface (Girija et al., 2023). Increasing a wheel contact area with the surface allows the vehicle to distribute its load over a larger area.

Typical Martian rovers consist of a six-wheeled rocker-bogie suspension (Shrivastava et al., 2020), which is a type of suspension system that uses springs and dampers, allowing rovers to keep all their wheels on the ground when traversing rough terrain. Rover wheels usually include parallel grousers (Nagaoka et al., 2020), or outward protrusions along the side edge of a wheel that increase traction on loose soil. Both Spirit and Perseverance are examples of rovers that have parallel grousers, as shown in Figure 7, and a rocker-bogie suspension system (National Aeronautics and Space Administration, 2003).

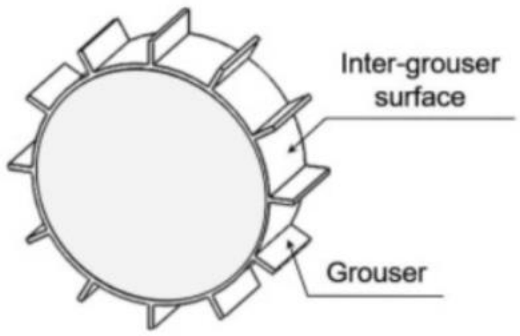

Figure 7: *Schematic Diagram of Wheel.* This image shows a diagram of a wheel with parallel grousers.

Current Extrication Methods and Their Limitations

When rovers get stuck on another planet, extrication methods rely heavily on human commands sent from mission control on Earth; however, this has proven to have low success rates and higher costs (Yang et al., 2025) because of the time delay when relaying commands and lack of situational awareness. It takes 4 - 24 minutes for radio signals to travel from Earth to Mars, causing a 8 – 48 minute delay in the command and response. Limited visibility of the rover's surroundings can cause its condition to deteriorate further. The Spirit Mars Exploration Rover prematurely ended its mission when it got stuck in a Martian sand trap (Jet Propulsion Laboratory, 2009). Ground-based extrication methods were employed but proved ineffective in this situation. A built-in autonomous self-recovery system would allow future rovers to detect immobilization and recover independently, without the intervention of mission control.

Competitor Analysis

Currently, many major space exploration companies are in the process of developing alternative wheel designs or improving traditional rover wheels to help planetary rovers better adapt to granular terrain. Some examples include NASA's Shape Memory Alloy tires and the Tensegrity Robot tires developed by the Adaptive Robotics Laboratory, both of which look at deformable tires that can adapt to the dynamic Martian terrain. Georgia Institute of Technology has also developed a more active method of locomotion, where their rover’s wheels are attached to appendages that allow the rover to lift and wiggle its wheels, helping it extract itself from sand traps. However, in the event of an embedding in the Martian surface, these locomotion methods would still rely on commands from ground control to be activated, which has proven to be largely ineffective. While my project will look at similar deformable wheel designs, the primary focus will be on making the extrication method autonomous, allowing the rover to operate independent from mission control and increasing the lifespan of future in-situ Mars exploration missions.