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Development of a Conceptual Design for a Future Mars Rover Mission

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Abstract

Mars is a widely unexplored planet with few rovers able to gather data on Mars. To hasten the progress of interplanetary research, we as humans need to develop the technology to explore other planets. The current solution is to send vehicles to planets such as Mars. Space Agencies such as NASA have been sending rovers and landers to mars for years. The scientists' effort has brought forth a lot of data about the red planet, and without them, these results could not be possible, and more innovation is needed to continue. Rovers are very complex but can simplify tools within subsystems within the entire rover system. It's detrimental to the function of the rover that every tool performs perfectly. With the development of a conceptual design for this rover, we could significantly decrease the time it would take to uncover the mysteries of Mars. In this paper, I researched details about previous rover missions to figure out a new plan to send a rover to mars. This outline includes the rocket for taking the rover to mars, the landing sequence, the landing location, the path the rover should take, and a basic understanding of what the rover would include and how it would appear. In addition to finalizing a landing location and identifying all working systems, the rover design (shown in the figures below) passed the computational tests with minimal stresses when applied when simulating forces present on Mars.

Keywords: Rover, Mars Rover, Space Exploration, Mars Mission, Mars Exploration, Space Rover, Planetary Rover

1. Introduction

1.1 Problems (Problems of Current Mars Exploration)

As the current situation is now, it would take humans many more years to even set foot on Mars with the numerous constraints placed on space programs worldwide. The feat of controlling three concurrent Mars rovers working as of today (August 3rd, 2022) is extraordinary, but setting foot on Mars within this era is impossible unless more unmanned vehicles are launched. Mars rovers are specifically crafted to work on its terrain but have sacrificed speed to reach that level of precision in their movement. The solution to the sluggish rate of exploration is to send more rovers to mars --covering more area within the same amount of time. The caveat to this solution is the years of planning and dozens of years' worth of funding needed.

Mars is possibly the single alternative planet in our solar system that could support life due to its position in our solar system, capability to support organisms, proof that water was once on Mars, etc. That was all in the past. Mars, now, is a barren wasteland and sports a toxic atmosphere. This atmosphere causes Mars to have countless dust storms and other phenomena similar to earth. These characteristics of Mars only make the planet harder to traverse with a vehicle. Since Mars is 140 million miles/225 million kilometers away from Earth, there is only one chance to send a rover there before returning to the drawing board.

1.2 Background

Mars has a very light atmosphere, approximately 1% of Earth's atmospheric density, yet it is very toxic as it is composed mainly of carbon dioxide. Because of its low atmospheric density, the environment on Mars is very extreme in terms of pressure, temperature, and wind. The temperature of Mars fluctuates throughout the day by 40 degrees Celsius on average: the coldest temperature being -107 degrees celsius in winter and -18 degrees celsius in summer. This vast temperature difference is due to the perihelion and aphelion distances. Because of the temperature differences between seasons, carbon dioxide at the poles condenses during winter and sublimes during summer. The pressure changes diurnally are unique to its environment. Because of the pressure variation, the wind speed is also very extreme. Wind speed varies between 2 and 7m/s in summer to 5-10m/s during winter. Similar to tornadoes on Earth, Mars has dust storms during which the wind speeds up to 30m/s.

The topography of each hemisphere of Mars is also vastly different. The southern hemisphere consists of heavily cratered Highlands. In contrast, the northern hemisphere is smooth and has clear indicators showing separations between sedimentary, volcanic, and Aeolian materials. This difference impacts the planning of the rover's mobility system when driving on mars.

History and Innovation of Rovers

To understand how to improve the design of rover missions, further inspection of past rover missions is needed. The first rover sent to Mars was the Pathfinder rover in 1996. It completed basic tasks: taking pictures, performing chemical analyses of rocks and soil, and collecting data on winds and other weather factors.

The second and third rovers sent to Mars were the Spirit and Opportunity rovers in 2003. They performed the same tasks as the Pathfinder rover except with updated technology to take higher resolution pictures and find more data to support the previous theory that Mars used to have a habitable atmosphere. In addition, it also analyzed the chemical and mineralogical makeup of rocks and soil and examined the interior of rocks.

The next rover sent to Mars was the Curiosity rover in 2011. This robot was jokingly said to be a lab as it has many more scientific tools to aid in data collection. Specifically, it has 17 cameras, a laser to vaporize and study small pinpoint spots on rocks (at a distance), and a drill to collect powdered rock samples. It hunts for clasts that may have formed in water or have signs of having organic material in them. As the previous rovers have indicated, it analyzes the powdered rock samples to find the chemical fingerprints in different rocks and regoliths to determine the composition and its history (past presence of water).

The next rover launched was the Mars 2020 Perseverance rover. Because of past findings from previous rovers, the Perseverance rover's main job is similar to the Curiosity rover, so there was no need to update its overall design, with only its technology needing to be updated.

The most significant innovations between rovers are the power and mobility systems. From the Spirit and Opportunity mission to the Curiosity rover, the power delivery system has changed from solar power to nuclear generators. The solar panels are prone to environmental problems like dust tornadoes that could have caused the rover to lose energy because the dust-covered solar panels cannot produce electricity while it's covered. Sending another rover with solar panels after they realized the mistake would only be more problematic since they would have to figure out how to clean the solar panels. The mobility system improved from a simple 6-box wheel drive train to a 6-wheel rocker-bogie suspension system to aid the rover's travels. The other difference between rovers is the scientific tools onboard. With each iteration, the rovers housed improved cameras and geological analyzers based on previous missions; it also formatted its instruments specific to each expedition. For example, the Pathfinder rover got the first pictures of Mars on the surface and analyzed the planet's makeup. Every rover after the Pathfinder rover attempted to confirm the Pathfinder's findings and explore new theories: oxygen content on mars and signs of water in minerals. (Dubov, 1997)

Table 1. Comparing the 3 current mars rovers (Beck, 2021; Serveveda, 2022; Liu, 2021;Liu, 2022; Mars.nasa.gov, 2022; Owlapps, 2022)

Names of Current Mars Rovers	Curiosity	Perseverance	Zhu Rong
Launch Date	November 06, 2011	July 30, 2020	July 23, 2020
Date landed	August 05, 2012	February 18, 2021	15 May 2021
Coordinates landed at	4.5895 degrees south latitude and 137.4417 degrees east longitude.	18.44°N 77.45°E / 18.44; 77.45 (Octavia E. Butler Landing)	109.925° E, 25.066° N at an elevation of −4,099.4 m
Location Name	Gale crater	Octavia E. Butler Landing	
Operation time (SOLS)	3512	477	Till today
Distance traveled	16.2 miles	7.32 miles	1500 kilometers (as of Jan 31, 2022)
Number of Parameters measured	4	3	5

The designs of rovers have drastically improved since the first rover on Mars. The rovers increased in size,

Vol. 2023 (2) 13 – 27
ISSN 2688-3651 [online]

weight, tools aboard the rover, and overall life span. The first rovers on Mars, the Pathfinder and Sojourner rovers sent in 1996, were 65 cm long vehicles, 48 cm wide, 30 cm tall, and weighing 10.5 kg. It was also solar-powered, so its functionality was limited. The distance it was allowed to travel was also limited because it would not work outside their lander's vicinity. They both only operated for 83 sols(85 earth days) and 92 sols (95 earth days), respectively. A sol is approximately 24 hours and 37 minutes on earth. The two newest rovers from NASA, Curiosity and Perseverance rover, are tank-like compared to the first rovers, both sizing at 3 meters in length, 2.7 meters in width, and 2.2 meters in height and weighing in at 1025 Kg and 899 Kg, respectively. Both rovers are still operational after landing on August 05, 2012, and February 18, 2021, respectively. Their long lifetime is thanks to the switch from solar power to nuclear power because it would work during long-lasting dust storms that would leave solar panels powerless. Another notable innovation of the rovers is the mobility system, which has now changed from a 6-wheeled system into a rocker-bogie system because of its ability to traverse many different terrains. (Mars.nasa.gov, 2019).

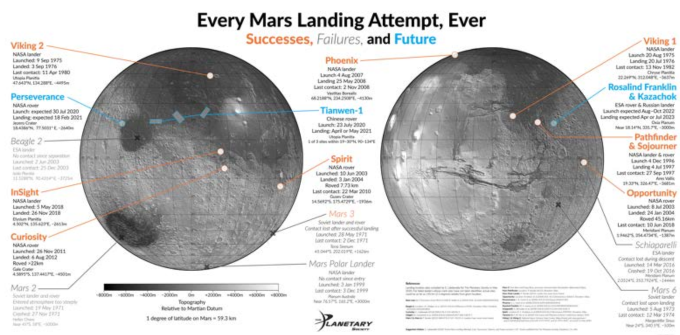

Figure 1. This figure shows where missions were attempted to land on Mars, successful missions are the boxes, the failed missions are the x's, and the future missions are circles (Lakdawalla & McGovern, 2020).

Understanding where and why other Mars missions failed is crucial to bettering future attempts. Looking at figure 1, there are many failed missions meaning many reasons for failing. One of the failed missions, The Beagle 2 lander (launched on June 2, 2003), lost connection to mission control as it entered Mars' atmosphere. Scientists have speculated several causes: an abnormally thin atmosphere over the landing site, electronic glitches, a gas bag puncture, damage to a heat shield, a broken communications antenna, and a collision with an unforeseen object. NASA found the lander on the surface of Mars 10 years later with its Reconnaissance Orbiter in 2013. Controlling as many variables as possible during the mission is crucial because there is only one chance to send that rover into space. Curiosity and Perseverance rovers have been successful because Nasa engineers could control more variables to minimize risk and improve the precision with advanced technology.

Subsystems of Rovers

A working rover has many subsystems. The subsystems are:

- Electrical Power: This subsystem controls power delivery during the entire mission. It includes powering all the other subsystems and maintaining a certain power level to ensure no failures happen. The rover cannot survive long using batteries, so a generator is needed to supply power. Most rovers to this day use nuclear generators.
- Structure: The rover's structure has to be manufactured to complete its mission. It has to be able to carry all the data-collecting instruments. The robot must also be able to protect its scientific instruments despite facing a partially unknown topography.
- Data Handling: This subsystem makes sure whatever data is stored and communicated quickly because of the volatile environment around the rover. The chance of losing valuable data is worse than losing the rover. This subsystem is directly tied to the telecommunications subsystem.
- Telecommunications: The telecommunications system is a two-way wireless UHF(Ultra handling frequency) radio link between a transmitter (lander or satellite) and receiver (rover). This link sends signals directly by first sending them to the proxy. Essentially it works like a walkie-talkie radio system between the lander/satellite and the rover.
- Temperature control: The rover uses a warm electronics box (WEB) to make sure that the robot's electronics can be used in the freezing conditions of Mars. This box is made out of aerogel (essentially a super insulator with a density of 1/50th that of water) to make sure the electronics can function while keeping it between -40 deg C and +40 deg C.
- Environmental Protection: Due to the cold atmosphere of Mars, teams at Nasa made several innovations to ensure its functionality, including low-temperature actuators and lightweight aluminum structures. This specific subsystem is also closely tied to the structure because the exterior has to withstand external conditions while maintaining a safe environment internally.

Vol. 2023 (2) 13 – 27
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- Mobility: The mobility subsystem has to aid the main body by allowing it to maneuver around mars freely while keeping itself intact. For instance, with the Rocker-bogie suspension system used in the previous 2 NASA rovers, the rover can move freely and over obstacles without springs (because of their fragility).

Design Schematics of Current Rover Systems and Their Scientific Tool

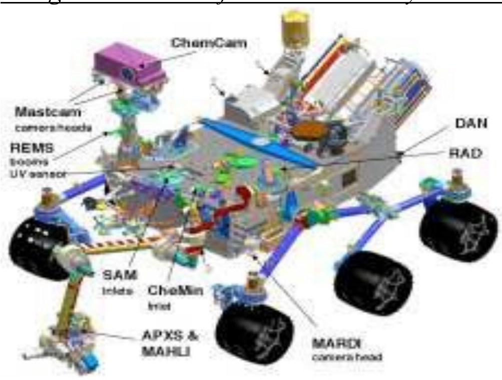

Figure 2. This figure is a schematic of the Curiosity rover with its scientific instruments pointed out (NASA/JPL-Caltech, 2011).

The Curiosity rover, shown in Figure 2, has countless scientific tools on rovers using a schematic of the rover itself. Some are the Chem Cam, DAN, RAD, MARDI camera head, APXS & MAHLI, CheMin, SAM, REMS, Mastcam, and MEDLI. The ChemCam (Chemistry and camera) is “An instrument that first uses a laser to vaporize materials then later analyzes their elemental composition using an onboard spectrograph. The DAN (Dynamic Albedo of Neutrons) is a pulsing neutron generator used to detect water content as low as 1/10th of 1 percent and resolve layers of water and ice beneath the surface. The RAD (Radiation Assessment Detector) is an instrument that measures and identifies all high-energy radiation on the Martian surface: protons, energetic ions or various elements, neutrons, and gamma rays. The MARDI is a camera that took color video during the rover's descent towards the surface, providing an “Astronaut's view” of the local environment. The APXS(Alpha Particle X-Ray Spectrometer) is a spectrometer that measures the abundance of chemical elements in rocks and soil. The MAHLI (Mars Hand Lens Imager) is a camera that provides earthbound scientists with a close-up view of the minerals, textures, and structures in Martian rocks and the surface layer of rocky debris and dust. The CheMin (Chemistry & mineralogy X-ray diffraction) is an instrument that identifies and measures the abundance of various minerals on Mars. The SAM (Samples analysis at Mars instrument suite) is a suite of scientific instruments that searches for compounds of the element carbon associated with life and explores ways in which they are generated and destroyed in the martian ecosystem. The REMS (Rover Environmental Monitoring Station) is an instrument that measures and provides daily and seasonal reports on Martian weather. The MastCam is a camera that takes color images and video footage of the Martian terrain. The instrument is also used to study the Martian landscape and support the driving and sampling operations of the rover. The MEDLI (Mars Science Laboratory Entry Descent and Landing Instrument) is an instrument that collected engineering data during the spacecraft's high-speed and hot entry into the Martian Atmosphere. (Mars.nasa.gov, 2019)

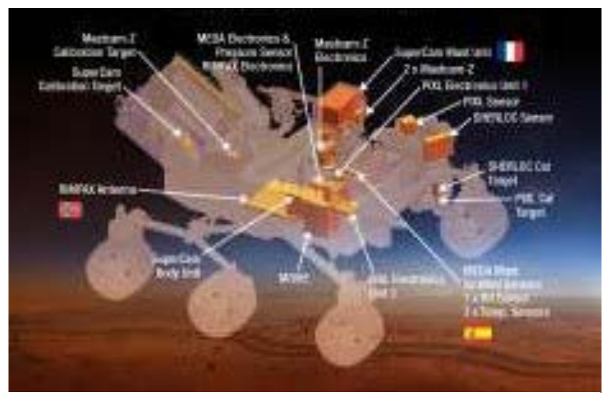
Figure 3. This figure is a schematic pointing at each of the tools atop the Perseverance Rover. (The anagrams are anagrams for the tools and will be explained in the following paragraph). (NASA/JPL-Caltech, 2020)

The Perseverance rover, shown in Figure 3, has many different scientific tools and different tools compared to the Perseverance rover's predecessor, the Curiosity rover. Some of the instruments on the Perseverance rover are the same technology on the Curiosity rover but innovated to increase quality and efficiency. The Perseverance rover still has a Mastcam abroad which is now called Mastcam-z. The new technology includes the MEDA (Mars Environmental Dynamics Analyzer), a set of sensors that will provide measurements of temperature, wind speed, direction, pressure, relative humidity, dust size, and shape. Another new technology is the MOXIE (Mars Oxygen ISRU experiment), an exploration technology investigation that will produce oxygen from Martian Carbon Dioxide. The PIXL is an X-ray fluorescence spectrometer that will also contain an imager with high resolution to determine the fine-scale elemental composition of martian surface material. It will also provide capabilities that permit enhanced detection and analysis of chemical elements than ever before. RIMFAX is also a new technology aboard the rover. It is a ground penetrating radar that will provide centimeter-scale resolution of the geologic structure of the subsurface. The SHERLOC, a spectrometer that provides fine-scale imaging and uses an ultraviolet laser to determine fine-scale mineralogy and detect organic compounds, also boards the Perseverance rover. SHERLOC will be able to be the first UV Raman

Vol. 2023 (2) 13 – 27
ISSN 2688-3651 [online]

spectrometer to fly to the surface of Mars and will provide complimentary measurements with other instruments in the payload. The newest camera, the SuperCam, provides imagery, chemical composition analysis, and mineralogy. This instrument can also detect the presence of organic compounds in rocks and regolith from a distance.

Landing locations

NASA's high-interest places, shown in Figure 4, are the SW Melas basin, Holden crater, Eberswalde Crater, Mawrth Vallis, Mili Posse, North East Syrtis Major (NE Syrtis), Jezero crater, and Columbia Hills (Gusev Crater). The criteria for choosing a spot to land has a lot of conditions, for example, "can the rover achieve all the missions' scientific objectives at this place?" or "does this area even have a high variety of soil for the rover to rest and could one of the different soils on this land have supported microbial life before?" etc. (Mars.nasa.gov, 2020).

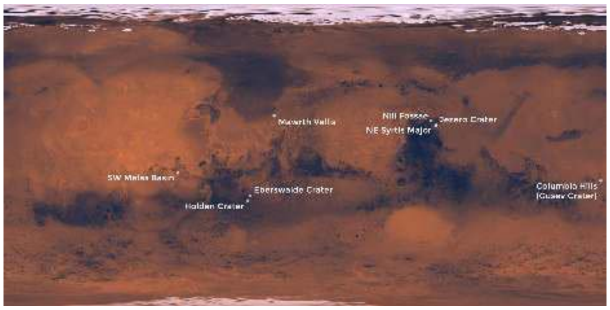

Figure 4. Nasa's 8 highest priority potential landing locations on Mars (NASA/JPL-Caltech, 2015).

Descent of Rovers

The landing sequence, shown in Figure 5, shows the steps that both the Perseverance and Curiosity rovers took during their descent to Mars. The landing sequence of the Perseverance rover is a perfect copy of the landing sequence of the Curiosity rover showing it was the best sequence for transporting rovers. The stages are as follows: after flying through space and entering the Mars atmosphere, the transportation module holding the rover first deploys a parachute to slow down its initial speed going into the atmosphere. After reaching a safe speed, the main shell separates from its heat shield and activates its radar and mobility boosters to ensure it's going the right way. After that stage, it separates from its backshell. After careful maneuvering, it touches down, and the device used to let it touch down flys away.

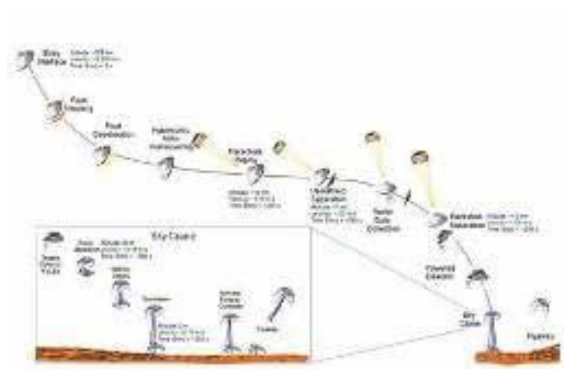

Figure 5. This graphic portrays the sequence of events in August 2012 from when NASA's Curiosity rover, enters the Martian atmosphere to a moment after it touched down on the surface. (NASA/JPL-Caltech, 2010)

Literature Review of Similar Papers

Within the intersection of Aerospace engineering and Robotics, researchers and scientists published hundreds of papers and patents to innovate on current systems. Looking at these ideas, understanding why engineers made specific choices becomes clearer.

A paper from NASA Glenn Research Center called Exploration Rover Concepts and Development Challenges presented an outline of exploration rover concepts and the various development challenges associated with each as they apply to exploration objectives and requirements for missions on the Moon and Mars. It also provided a brief description of the rover concept proposals since the initial development of the Apollo-era lunar rover, along with a comparison of their relative benefits and limitations. This paper also evaluated developmental challenges such as environment, atmosphere, and design obstacles to ensure the vehicle's protection. Finally, this paper details a modular concept for lunar and martian rovers launched as remote-controlled rovers shifting into astronaut-driven vehicles. This paper gave background information to analyze rover protection systems and put Mars's destructive weather and challenging atmosphere into perspective (Zakrajsek et al., 2005).

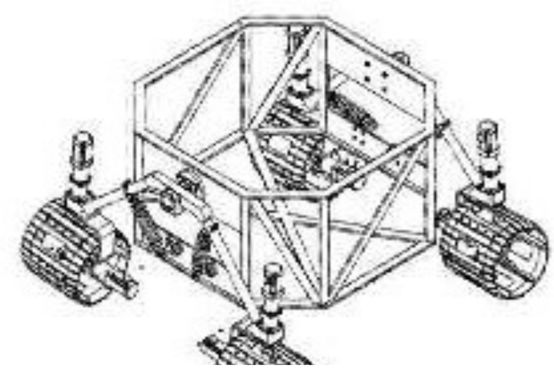

Figure 6. This is a picture of the patent by the researchers at Chongqing University (刘 et al., 2017)

Another paper, 3DROV: A Planetary Rover System Design, Simulation, and Verification Tool by scientists at the European space agency, builds upon current simulation technology to simulate an entire rover mission, covering everything from the planet's environment to the rover's electrical systems. The development of this technology benefits everyone, from amateurs to professionals, to simulate rover missions in real time versus separate computational tests. (Poulakis, 2008)

The unconventional patent which let me think outside the box for the rover design was a patent by researchers at Chongqing University.

The Chinese researchers' design, shown in Figure 6, although being just a shell, is unlike all the other Martian rovers. This rover has an octagonal chassis base and uses springs for suspension. This rover utilizes swerve drive, a mechanism granting free mobility, to traverse the surface, causing more stress on the battery than a 6-motor chassis. Without proper dimensions, determining this rover's payload capacity becomes difficult. In any case, it is not by any means a bad design. The design is different and requires testing to finalize the results (刘飞et al., 2017).

2. Materials and Methods

2.1 Research on Previous Missions

To understand how to make a new mission, we first must identify what all previous missions did to make it happen. First needing to identify all the challenges of each rover on the planet. In our case, it would be on Mars. Mars has a very light atmosphere which causes the environment to be a lot more extreme in terms of pressure, temperature, and wind. It also has a lot of variation in the land from the southern hemisphere having highlands and heavily created to the northern hemisphere having very smooth land and indicators showing sedimentary, volcanic, and aeolian material. Using this information, we know that the rover has to be able to overcome severe temperature fluctuations, so the necessity of an insulating box around the electronics is key to prolonging the life of the onboard computers/electronics. We also know that the rover has to not be able to be blown in the wind of Mars. To test, a design would need to be placed into a wind tunnel to simulate the extreme wind. The rover itself has to be able to traverse many different terrains because of the vastly different topography of Mars.

The missions of the new martian rovers are fundamentally the same: looking for past signs of life by attempting to identify environments capable of supporting microbial life. It will also seek signs of possible microbial life in rocks and minerals known to preserve organisms over time. The missions also include collecting core rock and “soil” samples and storing them on the Martian surface. By preserving samples on Mars, humans will be better prepared for testing oxygen production from the Martian atmosphere.

2.2 Payload Capacity of the Rocket

Before developing a rover's design, it's crucial to establish a plan to carry the rovers to mars. For the last ten years, the Atlas V 541 rocket took the two rovers from NASA sent to Mars because it has a maximum payload capacity of 6.28 metric tons in GTO Payload 1500 m/s to GEO configuration, and up to 8.29 metric tons in GTO Payload 1800 m/s to GEO configuration. There are other things to consider when landing the rover referenced in the landing section of the background, so these limits are crucial even though the rover is half of the limited weight.

2.3 Plan for the Mission

After finding how the rover will get up to the red planet, we have to figure out where it will land on the red planet. The next step is finding a location for the rover to land. From the Landing locations portion of the introduction (1.2.4), it's known that NASA currently has 8 high priority landing locations. The Jezero crater has one of the highest chances of completing all the missions because of its history of having fluctuating levels of water inside it. Because of the draining and refilling cycles, clay deposits were likely to be formed and may exhibit signs of past microbial life. NE Syrtis is the second best place to land because it has shown volcanic activity before. Another supporting factor for NE Syrtis is that it had ice around it, and that ice would melt and would have been a paradise for microbial life. Some organisms don't even need sunlight to survive, but they would rely on the energy of volcanoes instead.

The way to figure out how to traverse those areas is to sketch an initial path for the rover and have drivers and scientists use the topography of a map of Mars to find obstacles. The initial route aims to try to scout the most area for the least amount of distance traveled.

Before sketching a path, the distance the rover can travel within a period has to be established. After looking at previous rovers' timelines, the rover stays stagnant for long periods to give more power to processing and communicating data. For the Curiosity rover, the average drive length was 28.9 meters after 622 completed out of 738 attempted drives, according to a paper from NASA. The rover's movement took place over 2488 sols. The total distance driven by the rover is 21318.5 meters. Since this is the longest-running, currently operational rover, the ratio of traveled distance to the number of sols run provides an extensive trial of information that can be applied in other rover applications to extrapolate what distance the new rover can travel within 100 sols. (Rankin, 2020)

2.4 What is Needed to Make the Rover Work

Many tools and electronics are needed to make the rover work, and each instrument and device falls under a unique subsystem that would work almost independently of the other subsystems. For example, the power supply subsystem would need a battery, generator, and power splitter to make it work. For rovers, we need a way to get power, move around, and protect against the environment. Understanding the array of tools is crucial to complete all the different missions for the rover. A functionality matrix can track the tools within each subsystem to provide a holistic view of the interactions between subsystems.

2.5 Conceptual Design for the Rover

With the knowledge of what the rover should have inside of it and how it will move around, assembling the subassemblies should be easy. Since the Perseverance rover launched recently, an insignificant amount of mechanical innovations are possible, so the rover would look almost identical to the Perseverance rover. Although the rovers would be mechanically identical, the scientific tools within the rover would be more advanced.

Specifically, the rover needs to have a rectangular body with a rocker-bogie mobility system, a stationary camera on top of it, and a robotic arm that can drill into the surface and extract samples. It also needs to be able to leave mineral samples behind to not slow down the rover over time.

The outside of the body of the rover has to be covered in sensors to determine its location and move accordingly. After all, many environmental variables could impact the encoder feedback from the wheels.

For most of the complex parts of the rover, grabcad.com was used to find the more complicated designs that would take a long time to design by hand (this includes the rocker-bogie chassis, wheels, etc.). Although an extensive website, grabcad.com does not have all the parts needed for the rover, NASA has enough drawings and models to extrapolate a basic shape from the complicated parts. At this point, Autodesk Inventor was used to designing each of those parts by hand to undergo the stress analysis (the rover arm, the outer casing of the rover, the robotic arm, etc.). (Croston T. 2014)

2.6 Tools on Rover

Many things are not essential in the CAD design but need to be included in the rover, like the scientific tools (because it is housed within the main body of the rover). The essential instruments a rover would need are a camera and microphones to know more about Mars' topography and the sounds of the environment around it. The rover would also need tools to extrapolate atmospheric data, so there would be a suite of weather-related instruments to understand the temperature, wind speed, and other things. Another goal of the rover is to understand the mineralogical makeup of the surface of mars, so the rover would need to include a chemical analyzer (a different one for the soil and one for the air), an x-ray or microscope to look closer at the composition and to see if the soil has bacteria in it, and a drill to collect the samples.

Vol. 2023 (2) 13 – 27
ISSN 2688-3651 [online]

2.7 Forces Acting on the Rover

Previously covered was the force of the wind on the rover. The strong winds on mars could make the rover susceptible to being blown away if the center of gravity of the rover is not low enough. Another force acting on the rover is gravity. When designing the rover, these forces need to be taken into consideration. To analyze its structural integrity, computational analysis within a CAD program to find a structure that could withstand the forces of Mars. The rover needs to be manufactured from low-density and high-strength materials to withstand the forces while being light enough to be transported.

2.8 Future Fixes to the Design

The plan is rudimentary, not delving deep into each topic but analyzing information on a surface level. For example, the landing location data came from only a few sources. The decision matrix was made using qualitative judgment based on research done by other universities and interpreted as quantitative data based on the advantages and disadvantages of each site. The rover paths were also sketched from judgment on Google Earth's map of mars based on where they should move to complete each mission, cover as much surface area as possible, and avoid elevation changes. With a more detailed map, these paths can be further advanced. Another future improvement would be the design of the rover, but because of time restraints, many aspects of the rover could not be modeled and were generalized. A crucial fix is to add joints and fix inefficiencies before assembling all subsystems. Other changes would be insignificant in comparison but important nonetheless. For instance, changing the computational design would be to include fasteners in as many places as possible and run more simulations with different forces to understand the stress points on the rover.

3. Results

3.1 Decision Matrix Results

This decision matrix was filled out based on research of other studies and information on NASA’s website. Table 2 shows how I interpreted the information that I have seen. In this case, the location with the higher total number is the most favorable since it would be able to complete each mission question the most as a rover can do.

Table 2. This decision matrix was used to decide the optimum place to land a rover. It uses the mission questions as criteria; means that the location can barely fulfill that question; means that it fulfills the questions' requirements; means that it excels in this question's criteria.

Place Name (points = pnts)	NE Syrtis	Jezero Crater
Does the area show signs in the rock record that it once had the right environmental conditions to support past microbial life? (7 pnts)	5	7
Does the area have a variety of rocks and "soils" (regolith), including those from an ancient time when Mars could have supported life?(7 pnts)	7	3
Did different geologic and environmental processes, including interactions with water, alter these rocks through time?(7 pnts)	7	5
Are the rock types at the site able to preserve physical, chemical, mineral, or molecular signs of past life?(7 pnts)	7	7
Is the potential high for scientists to make fundamental discoveries with the samples cached by the rover, if potentially returned to Earth someday? (7 pnts)	5	5
Does the landing site have water resources (water ice and/or water-bearing minerals) that the rover could study to understand their potential use by future human explorers? (7 pnts)	7	7

Vol. 2023 (2) 13 – 27
ISSN 2688-3651 [online]

3.2 Rover Pathing

$$\frac{21318.5}{2488} = \frac{D}{S} \tag{1}$$

Equation 1 shows how far a rover can move in a certain amount of sols. Where ‘S’ is the number of sols traveling and ‘D’ is the total distance traveled in meters.

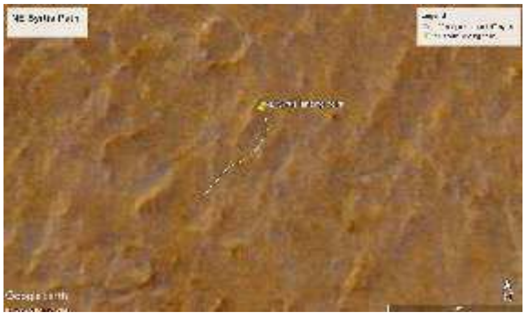

Figure 7. This Figure shows a path plotted for the 100 Sol mission in NE Syrtis. (Adapted from Google Earth)

Figure 8. This is a path plotted for the 200 Sol mission in NE Syrtis. (Adapted from Google Earth)

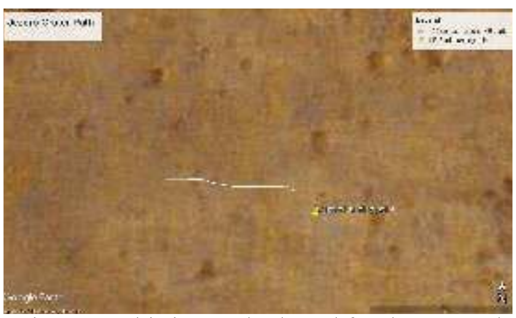

Figure 9. This is a path plotted for the 100 Sol mission in Jezero Crater. (Adapted from Google Earth)

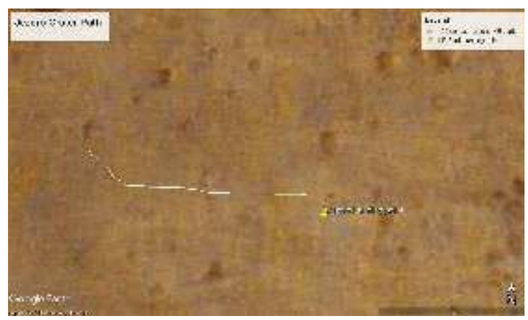

Figure 10. This is a path plotted for the 200 Sol mission in Jezero Crater. (Adapted from Google Earth)

Using Equation 1, in the case of a 100-sol trip, we can solve the distance to be approximately 856.85 meters Figures 7 and 9 show a path that allows the rover directly to get to the nearest change in the soil while staying in the range of 856.85 meters. Both paths have the lowest change in elevation to eliminate all factors that would hurt the rover. Figures 8 and 10 show paths that go on for 200 sols on Mars. It follows the same concept from Figures 7 and 9, but the distance doubled since the expected mission date doubled.

In NE Sytris, the rover is supposed to land at approximately 17°56'22.93"N, 77° 7'53.52" E. The end coordinates for the 100 sol journey are 17°55'41.62"N, 77° 7'26.28" E. The end coordinates for the 200 sol journey are 17°55'33.01"N, 77° 6'41.91" E. Within Jezero crater, the rover attempted to land near 18°28'24.12"N, 77°34'44.75"E. The end coordinates for the 100 sol mission are around 18°28'38.64"N, 77°33'35.06"E. The end coordinates for the 200 sol mission are around 18°28'50.82"N, 77°32'54.19"E.

Table 3. In the decision matrix adapted from the Reusable space tug concept and mission, shown in table 3, many things are vague or unexplained. The MMRTG is a Multi-mission radioisotope thermoelectric generator. The warm electronics box refers to the insulation box surrounding the electronics to prevent the electronics from freezing. The turret refers to the moving arm that collects samples.(NASA, 2020) The cameras refers to devices recording all types of light across the spectrum. The chemical makeup instruments are instruments such as ChemCam, DAN (Dynamic Albedo of Neutrons), RAD (Radiation Assessment Detector), APXS (Alpha Particle X-Ray Spectrometer), and CheMin (Chemistry & mineralogy X-ray diffraction). Whenever the word "elaborate" is used within the matrix, it means to be processed within the main computer of the rover (Cresto et al., 2016).

Vol. 2023 (2) 13 – 27
ISSN 2688-3651 [online]

Table 3. The functionality Matrix shows all subsystems of the rover and what instruments and technology are needed to make that subsystem work.

SYSTEM LEVEL	SUB-SYSTEM LEVEL	MMRTG	Batteries	Power distributor	Power converting unit	Shielding panels around computer	warm electronics box	Airless tires	Motors	Rocker-bogie suspension system	Rover body	Rover arm	Turret	Drill	Microphones	Cameras (all spectrums of light,	Chemical make up instruments	Environmental Analyzer	Command & Acquisition unit	On-board computer	Memory unit	Receiver	transmitter	auto-tracking equipment	GPS receiver	Gyroscope/internal measurement unit	body attached sensors	Main Computer	telecommunications unit
Electrical power	To perform power production	X																											
	To perform power storage		X																										
	To perform power conversion				X																								
	To perform power distribution			X																									
Environmental Protection	To protect from debris					X					X																		
Temperature control	To prevent frozen electronics						X				X																		
Mechanical (structure, mobility, etc.)	To Move along the surface							X	X																				
	To allow traversing any terrain									X																			
	To collect rock/soil/debris samples											X	X	X															
	To house electronics										X																		
	to store samples																												
Data collection	To collect visual data															X													
	To collect auditory data														X														
	to perform analysis on rocks/soil/debris																X												
	To collect environmental data (temperature, wind velocity, humidity, and dust)																	X											
	to collect data on atmospheric makeup																X	X											
	to collect crust elemental makeup data																X												
Data handling	To receive monitoring Data																		X										
	To validate monitoring data																		X										
	to elaborate monitoring data																			X									
	to store elaborated monitoring data																				X								
	to receive control data																		X										
	to validate control data																		X										
	to elaborate control data																			X									
	to store elaborated Control data																				X								
	to receive command data																		X										
	to validate command data																		X										
	to elaborate command data																			X									
	to store elaborated command data																				X								
Tele-communications	To transmit mission data																						X						
	To elaborate data to be transmitted																							X					
	to obtain data to be transmitted																					X							
	to transmit telemetries																						X						
	to elaborate telemetries																							X					
	to obtain telemetries																					X							
	to receive commands from earth																					X							
	to elaborate receive commands from earth																							X					
Navigation	to receive GPS coordinates																								X				
	to elaborate coordinates																											X	
	to transmit coordinates																												X
	to receive gyroscopic data																									X			
	to elaborate gyroscopic data																											X	
	to transmit gyroscopic data																												X
	to receive positioning data																										X		
	to elaborate positioning data																											X	
	to transmit positioning data																												X

Journal of Research High School
Vol. 2023 (2) 13 – 27
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3.4 Rover CAD Models and Stress tests

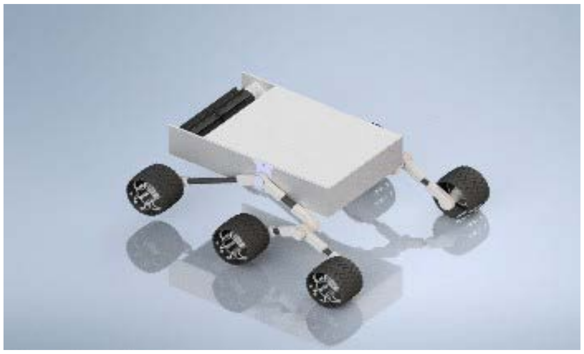

Figure 11. CAD render of v1 of rover

Figure 12. CAD render of finalized rover

The Computational designs, shown in Figure 11, show the first version of the CAD model of the rover. It missed components on top of the rover but displayed a relatively accurate look of the rover. Figure 12 shows when the camera and arm are attached to the rover. Both Figures 11 and 12 show the rover having a rocker-bogie chassis design. The MMRTG generator is at the back of the rover, and the cameras are at the front. The tires on these rovers are airless. The entire frame is theoretically made of aluminum. The computer would be located within the central box of the rover. Both of these designs are designed using Autodesk Inventor 2023.

$$F = mg \tag{2}$$

Equation 2. Force of gravity on Mars where F is force m is mass and g is the gravitational constant of acceleration on mars.

The force of gravity was the only factor taken into account for the stress tests for the rover models because that would be the bare minimum for traversing another planet. In this case, we are letting the computer handle the forces, and this equation is input into most of the stress tests taking place because we are only inputting gravity.

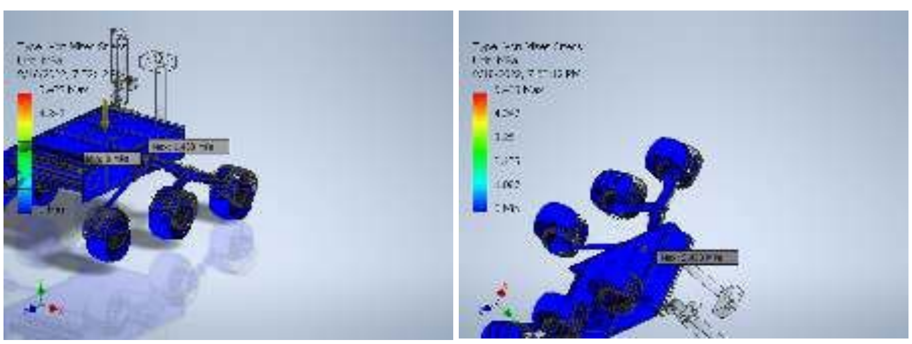

Figure 13. Von Mises Stress of Final Version of Rover.

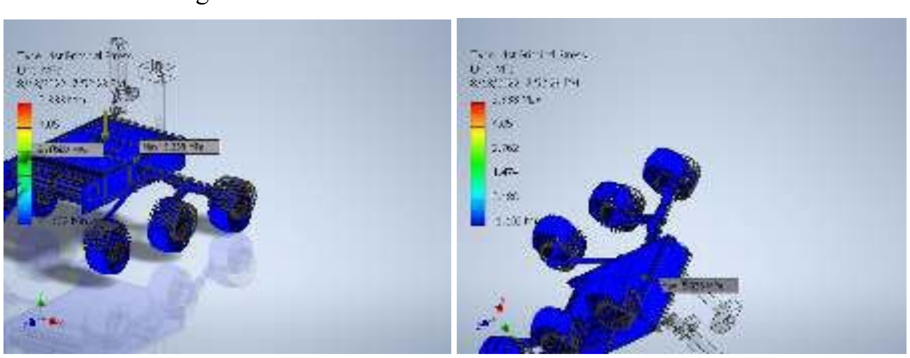

Figure 14. First Principle Stress of Final Version of Rover.

Vol. 2023 (2) 13 – 27
ISSN 2688-3651 [online]

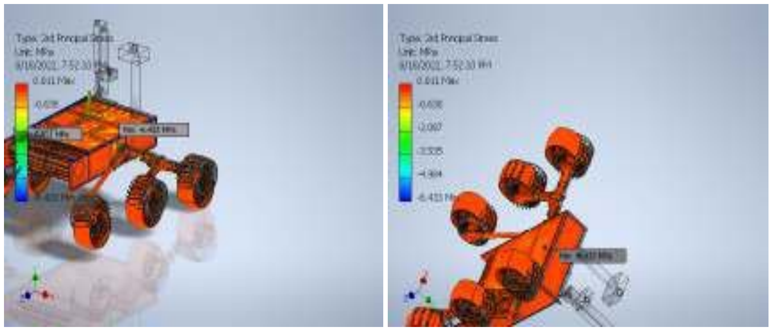
Figure 15. Third principle Stress of Final Version of Rover.

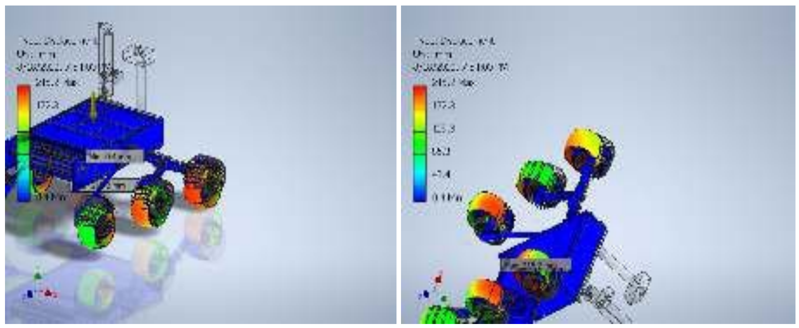
Figure 16. Displacement of Final Version or Rover.

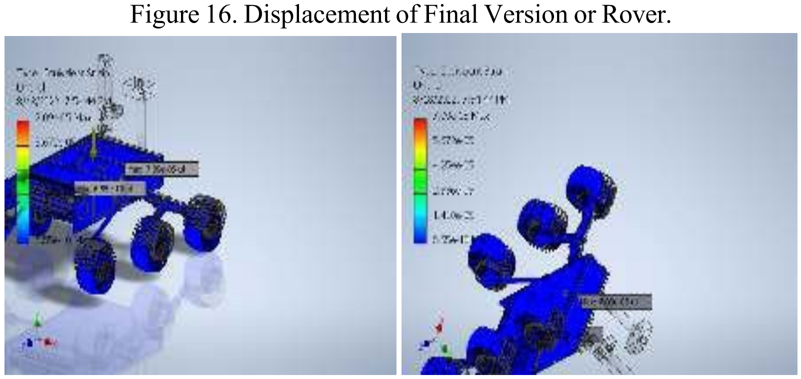
Figure 17. Equivalent Strain of Final Version or Rover.

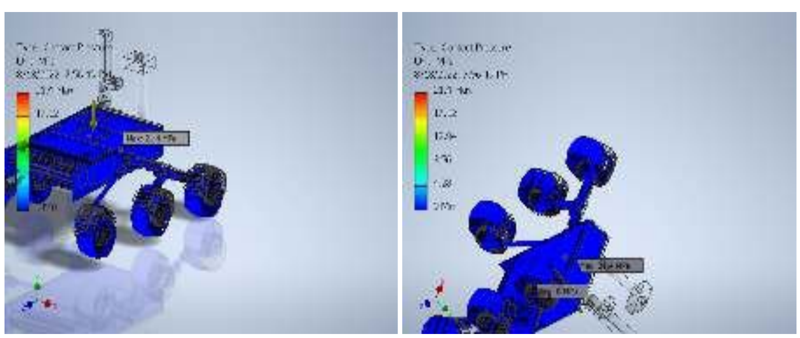
Figure 18. The Contact Pressure of the Final version of the Rover.

After adding more parts on top of the rover, 6 different stress tests were simulated using Autodesk Inventor. The Von Mises stress test results, shown in Figure 13, show a minimum value of 0 MPa, almost completely covering the outside of the rover. The places where the maximum value, 5.433 MPa, is shown are on the edge of the side plates and the inside. The Von Mises stress results, shown in Figure 24, have a minimum value of -1.102 MPa which also covers the rover except for a few spots on the top and bottom plate where it reaches a maximum of 5.338 MPa. From the third principal stress test results, shown in Figure 15, we can see that the maximum is 0.811 MPa, which also covers the rover and lessens on the top and bottom plates. The minimum for these stress test results is -6.433 MPa and not most likely on the inside surfaces of the rover since it is not visible on the outside. The displacement stress test results, shown in Figure 16, show a minimum displacement of 0.4 mm and a maximum of 215.2 mm. The Equivalent strain test results, shown in Figure 17, show a maximum value of 7.09e-05 ul and a minimum of 6.55e-10 ul. The minimum value covers the rover's exterior, so the maximum must be on the inside. The Contact pressure test results, shown in Figure 18, show a maximum of 21.4 MPa and a minimum of 0 MPa. Like the equivalent strain tests, the minimum covers the outside while the inside shows the maximum.

4. Discussion

4.1 Rover Paths

Many factors could affect the rovers driving on Mars. To decrease the number of factors, we plan a course with the lowest change in elevation so the rover can explore without worrying about falling on its back. In Figures 9 through 12, the paths are chosen to get to a new area of soil in as straight a line as possible to analyze different soil types quickly. In the case of NE Syrtis, on Google Earth's view of Mars, there is a difference in color and number of craters west of the landing point. The rover landing point was constructed to cross different soils on the longitudinal lines and reach a completely different soil sample almost simultaneously. For the Jezero crater, The reasoning within this path is to reach the Jezero crater delta, the place most likely holds the answer to our mission questions, but not run into any craters while getting there. That is why the rover heads west first.

4.2 Decision Matrix Results

For the first question of the Decision Matrix, NES(Ne Syrtis) received a 5, and JC(Jezero crater) received a 7 because JC has more theoretical evidence of life on mars due to its geographical formations. The JC being a crater also shows that it could hold water, supported by the fact that there is a delta-like feature on the northern lip. For the second question, NES received a 7, and JC received a 3 because JC shows fewer rock types versus NES due to its volcanic history. For the third question, NES received a 7, and JC received a 5 because JC had only theorized water on it while NES had both water and volcanic activity. Due to the rich abundance of water theorized in each location, both locations received a 7 for the fourth question. For the fifth question, both locations received a 5 because there aren't plans to retrieve the rover samples from Mars, but they would both get samples once there. Question six also relates to the water content theorized in both places, so both received a 7. Question seven is about the maneuverability of the rover. Both places received a 5 because of many challenges in NES due to its geography, but launching a rover in JC locks the operable area inside the crater. The decision matrix ended with NE Syrtis only 4 points ahead of the Jezero crater, an insignificant difference. The best choice would be NE Syrtis because it is not a finite area unlike the Jezero crater. In the end, NE Syrtis would most likely have the best chances of finding evidence of life because of different soils, past volcanic activity, vast amounts of water, and clay deposits.

4.3 Rover CAD design

The rover design is the most crucial aspect of a rover's mission. The computation model has to reduce as many variables as possible and be able to travel the longest distance possible. To accomplish this, remove springs in place of a Rocker-bogie suspension system because it can traverse obstacles without having a single spring in it. Another variable that can be removed is the air inside the wheels because it risks popping and leaving the rover stagnant. (Rajan, 2022) Using airless wheels eliminates the risk of getting a flat tire. One part not developed fully is the design of the arm. It needs to have almost complete freedom to collect samples. The frame is aluminum, allowing the rover to have the most strength for the least density. By cutting the weight, the rover can hold more instruments. In the case of this design, the MMRTG at the back is horizontal as opposed to on an angle on previous rovers, Curiosity, and Perseverance because it was the only generator file available to me on short notice.(Reed, 2018) The Rocker bogie chassis here is also not the best because where each axle is, there are supposed to be two motors that will move the wheel and any direction to achieve omnidirectionally. The wheels are from the Curiosity rover, which has passed through the test of time. By using the template of previous rovers, which has been tried throughout the years and shown long life, we can send rovers to Mars that would not become trash in a couple of years and be able to complete their missions within their lifetime.

4.4 Stress Test Results

The structure of the rover has to be strong enough to withstand the pressures on Mars. The simplest one to integrate is gravity.

In simplicity, Von Mises stress determines if a material will yield or fracture. In the Von Mises stress test results, shown in figure 13, the overall value throughout the rover is zero, telling us that the material chosen will not fracture under this pressure. Wherever the maximum value ends up, there will need to be more support in that area, especially on the inside.

First principal stress gives you the value of stress normal to the plane in which the shear stress is zero. Again in this test, shown in figure 14, the values throughout the rovers are zero indicating that the material will not break. The only places that are causes for concern within this are on the top where there is currently minimal support. This could be fixed by adding support structures throughout the central housing.

The third principal stress normally acts to the plane where shear stress is zero. It helps understand the maximum compressive stress induced in specific parts due to the loading conditions. The results of this test, shown in figure 15, are also similar to the first principal stress test results since the values hover around zero throughout the rover. Differing results are shown on the top paneling, indicating that more support is needed.

Displacement in a stress test is how far each specific part will move in relation to others and the forces acting on it. The displacement, shown in figure 16, of the rover, is the one part of these tests that are worrying because it seems that the wheels have fallen off. There could be a lot of circumstances that made the wheels not fully attach to the rover, but it is negligible because they are not fastened to the rover yet. This means that with proper assembly, the wheels would not fall off.

Equivalent strain is the limit for the values up to which the object will rebound and return to the original shape upon removal of the load. The equivalent strain, shown in figure 17, is almost negligible because it shows values of approximately 6.55e-10 ul. Wherever the maximum value ends up, there will need to be more support in that area, especially on the inside.

Contact pressure is the ratio of the normal load to the true contact area. In Figure 18, the contact pressure is also negligible since it's close to zero. Although these tests only use one factor to determine if they are concerns, it's useful to determine the base structural integrity of the rover, so adding more parts, tools, or scientific instruments would be easier.

4.5 Functionality Matrix Results

Table 3 contains information about the functionality matrix. The electrical power subsystem is to supply the entire rover with electricity to function. The environmental protection subsystem is vital to protect the robot from the harsh conditions of Mars. This subsystem works in tandem with the temperature control subsystem, ensuring the electronics function throughout the temperature fluctuations. The mechanical subsystem deals with all the raw robotics parts like structure and mobility. The data collection subsystem is arguably the most important because it's the one subsystem that gathers data on Mars. With the data collection, there needs to be a way to handle the data on board the rover. To send data to earth, the rover needs a telecommunications subsystem. To traverse Mars, a navigation subsystem is utilized so the rover and humans know where the rover is going. Without even one of these categories of electronics or tools, the mission would fail because it would be less than the bare minimum.

Vol. 2023 (2) 13 – 27
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5. Conclusion

In the end, Mars is just another planet in our solar system. Although widely unexplored, from the few times humans were able to explore Mars, there were still many discoveries that could help humans understand its history. Since humans can't get to Mars, the only way is to send a vehicle (rover) there to gather information for us. By sending more rovers onto the red planet, the more we can understand it at ground level. With more conceptual outlines of missions for these rovers, the less time it takes to understand the planet. There needs to be years of planning and more time building the rover itself. Ensuring everything will work beforehand is the key to making this mission succeed because once the engineers load the rover into the rocket, there is no going back to work on it. There are many years of plotting the path, designing the systems, perfecting the technology, building the equipment, and testing on earth, but there is only one chance to get to Mars. In conclusion, by preparing plans to send rovers to mars, we can reduce the time it takes to understand the planet and further advance our technology.

I would have liked to start from scratch and make the entire thing myself, but because of time constraints, it was improbable. I relied on past 3d models that would not have been what I was looking for. In the future, I recommend researchers find the most optimal path for the rover, hypothesize the robot landing the rover, make the rover drivetrain more mobile, and create a CAD design with all the necessary tools depicted on the outside.

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