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Design and Analysis of Mars Rover Wheel

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Abstract: This project investigates the design and analysis of Mars rover wheels, crucial components for successful Martian exploration missions amidst evolving technological advancements. Designed to traverse various surface conditions, including rocks and sand, the rover wheel incorporates a unique configuration with a leaf spring, enhancing its performance on challenging terrain. Utilizing advanced CAD and simulation techniques, the proposed design is comprehensively modelled and analyzed, presenting an innovative advancement in Mars rover wheel performance, and marking a significant stride in space exploration.
Keywords: Mars rover wheel, Surface conditions, Leaf Spring, Evolving technology

I. INTRODUCTION

Mars, known as the "Red Planet" has captivated space exploration efforts, leading to numerous space missions aimed at unraveling its mysteries. The Martian terrain poses numerous challenges, such as roughness and the presence of rocks and dunes. Therefore, developing effective wheel designs and analyzing their performance is crucial to ensure the rover's mobility, stability, and mission success. Among the missions, Mars rovers have played a vital role in advancing our understanding of the Martian surface. These rovers have provided us with close-up images, conducted scientific experiments, and collected data that has significantly contributed to our knowledge of the planet. Reference [1] shows modelled and analyzed a wheel using different materials such as aluminum-based silicon carbide particles and aluminium-based titanium fiber. As wheels are a key component of planetary exploration for rovers, the study assessed the radial stiffness, axial stiffness, torsional stiffness, and deflection stiffness to determine wheel performance under mission stress. Experimental results indicate that the aluminium-based silicon carbide wheel exhibits superior stiffness characteristics compared to the aluminium-based titanium fiber wheel, except in terms of axial stiffness. Reference [2] investigated the development of a single composite leaf spring for lightweight wheel vehicles. The study involved theoretical calculations to analyze various aspects of the leaf spring, including material properties, factor of safety (FOS), and load-carrying capabilities. Through these calculations, the design aimed to achieve a balance between weight reduction and structural integrity, facilitating the creation of a lightweight vehicle design with improved performance, enhanced fuel efficiency, and greater durability. Reference [3] investigated the stresses and deflection of composite leaf springs, comparing them to those of steel leaf springs. The study evaluated various materials for the composite leaf springs, including E-glass Epoxy, Carbon. Epoxy, and Boron Aluminum composites, in contrast to the conventional 55Si2Mn90 steel. Finite Element Method (FEM) analysis was conducted using Ansys 15.0 software to calculate deflection and von Mises stresses for the springs. The results demonstrated that leaf springs made from composite materials exhibited comparable strength to heavy steel springs. Reference [4] explores the utilization of small-wheeled rovers in planetary exploration, particularly focusing on their application in Mars missions to relieve cost and operational challenges.

This study aims to enhance the mobility of such rovers by investigating the relationship between wheel shapes and ground resistance forces the research endeavors to propose wheel designs that minimize ground subsidence when subjected to ground vibrations. Experimental tests conducted on loose terrain validate the correlation between wheel shapes and rover mobility, with results indicating improved performance using wheels designed to minimize ground subsidence. Reference [5] discusses the Rocker Bogie mechanism, comprising a rocker arm and bogie assembly meticulously designed to enhance stability and adaptability for Mars rover wheels. Theoretical calculations entail determining wheel dimensions, velocity, and lengths of rocker arms and chassis to ensure optimal rover mobility, stability on uneven terrain, and traction. Additionally, the paper presents a design addressing critical aspects such as material selection and fabrication techniques essential for establishing an effective rocker-bogie system. This study demonstrates the valuable insights gained from ANSYS analysis, which provides insight into the performance and behavior of both the leaf spring and the wheel. Through analysis of stress distribution, deformation, and safety factors, the design choices were validated, while areas for improvement were identified. These findings comprehensively understand the project's performance, laying a foundation for further optimization and refinement efforts. By looking at things like stress and how they bend, we can see if our design choices are good and find ways to make them better.

II. LEAF SPRING

A. Specifications of the Leaf Spring Model

The geometry of the leaf spring considered in this design and analysis is shown in Figure. 1. The material used is Magnesium RZ5 Alloy and all corresponding material and design data are presented in Table 1.

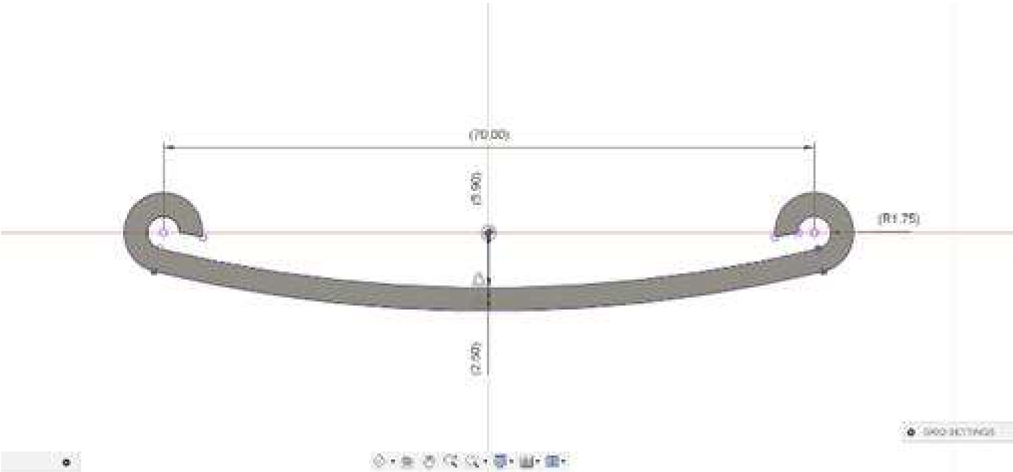

Fig. 1 The leaf spring

Table I - MATERIAL DATA

Sl. No.	Data	Details
1	Number of leaves	1
2	Thickness of leaf	2.5mm
3	Width of leaf	4mm
4	Total full length of spring	70mm
5	Young Modulus	44.1Gpa
6	Poisson's ratio	0.35
7	Tensile strength ultimate	245Mpa
8	Tensile strength Yield	218Mpa
9	Density	1820 Kg/m^{-3}

B. Strength Calculations

The calculations were performed using established engineering principles and equations relevant to leaf spring design and analysis. Acceleration due to gravity = 3.71 m/s^2

Factor of safety (FOS) = 1.1

Total weight = 24 N

Bending stress, $\sigma_b = \frac{3WL}{bt^2}$

Deflection, $\delta = \frac{\sigma L^2}{4Et}$

Were, W = load in N.

L = length of the spring in mm.

b = width of the spring in mm.

t = thickness of the spring in mm.

σ = stress (N/mm^2).

E = young's modulus (N/mm^2).

Table II- THEORETICAL CALCULATIONS

Load (N)	Stress (N/mm^2)	Deflection (mm)
24	100.8	1.122
25	105	1.169
26	109.2	1.216
27	113.4	1.262
28	117.6	1.309
29	121.8	1.356
30	126	1.403

III. WHEEL MODEL

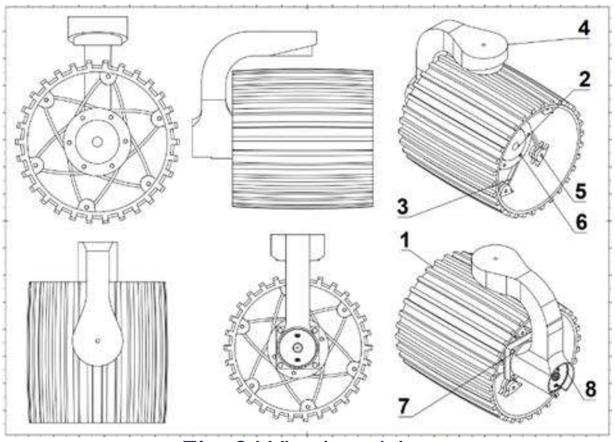

Fig. 2 Wheel model

TABLE IIII- WHEEL MODEL DATA

Part No.	Details		
	Part Name	Material	Quantity
1	Outer shell	Al Alloy, Wrought,6061, T6	1
2	Wheel hub	Al Alloy, Wrought,6061, T6	1
3	Leaf spring	Magnesium RZ5 Alloy	12
4	Pivot point	Al Alloy, Wrought,6061, T6	1
5	Outer shell to leaf Spring bolt	Ti-6Al-4V, Annealed	12
6	Wheel hub to leaf spring bolt	Ti-6Al-4V, Annealed	12
7	Wheel hub to motor hub bolt	Ti-6Al-4V, Annealed	1
8	DC motor	Metals	1

A. Wheel Calculations

V = $\frac{\pi DN}{60}$

Were, V = velocity in mm/s.
D = diameter of the wheel.
N = RPM.

TABLE III- WHEEL SPECIFICATIONS

RPM(N)	Velocity(mm/s)	Diameter(mm)
15	100	127.38

IV. MECHANICAL DESIGN OF THE MODEL

A. CAD Model

The 3D model of the wheel was designed using Autodesk Fusion 360 software.

Fig. 3 Iso-metric view of the model

Fig. 4 Front view of the model

V. FINITE ELEMENT ANALYSIS

In this project, ANSYS software was employed to analyze the leaf spring. The leaf spring geometry was meticulously modelled within the ANSYS environment, with stresses and forces calculated using ANSYS 2023 R1 software. Due to the inherent symmetry of the leaf spring, only half of the model was analyzed in ANSYS. The leaf spring geometry was discretised using a 0.5mm meshing technique, dividing it into numerous small elements to accurately capture structural behavior. This fine mesh size facilitated a detailed representation of the leaf spring's response to applied loads, allowing for accurate prediction of stress distribution and deformation patterns. Static structural analysis was performed, with boundary conditions applied based on operating conditions and material data. The analysis provided insights into the leaf spring's response to applied loads, evaluating its structural behavior. Total deformation indicated the extent of deflection and deformation experienced by the leaf spring under given loading conditions. The wheel's structural performance was analyzed in ANSYS, considering stress distribution and deformation under various loads. We utilized a 2mm mesh size for detailed modelling, ensuring accurate representation of the wheel's behavior. This analysis offers valuable insights into the wheel's ability to withstand different conditions, aiding in its optimization for enhanced performance.

VI. RESULTS AND DISCUSSION

A. Leaf Spring

The ANSYS analysis offers valuable insights into the performance and behavior of both the leaf spring and the wheel. Analysis outcomes, encompassing stress distribution, deformation, and safety factor, validate design choices while identifying areas for improvement. These results provide a comprehensive understanding of the project's performance, serving as a foundation for further optimization and refinement efforts. Fig. 5 depicts the static structural model of the spring, with a 12.5N load applied along FY in the downward direction. To simulate gravity's effect in ANSYS, we apply an acceleration load of +3.730mm/s². This is because in ANSYS, positive values in the Y component of the acceleration load correspond to downward gravitational force, ensuring accurate representation of mass movement. Figures 6 to 8 display the total deformation, safety factor, and equivalent von Mises stress. The theoretical/analytical values closely align with the simulation results obtained in ANSYS. The results obtained are presented in Table V. The calculations and analysis were conducted for the cantilever beam setup due to its inherent symmetry in nature. For the simply supported beam configuration, the values can be derived by doubling those obtained for the cantilever beam. Therefore, the bending stress being lesser than the allowable stress up to 25N (where the bending stress should be lesser than the allowable stress for the design to be safe) indicates that the design is safe. However, beyond 25N, it fails to meet the safety criteria.

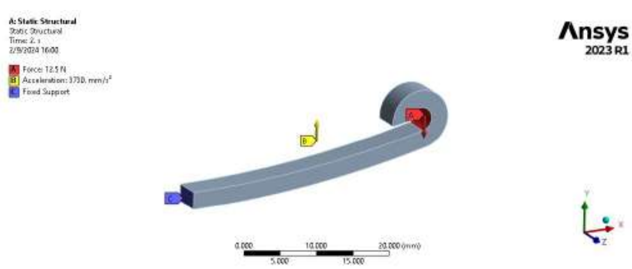

Fig. 5 Static structural

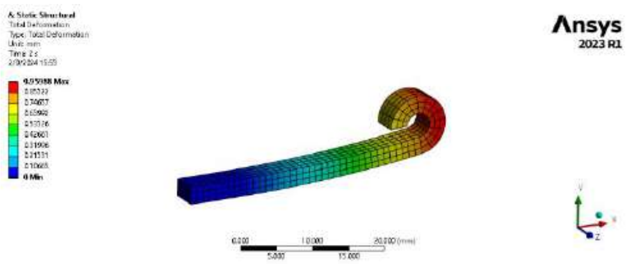

Fig. 6 Total deformation

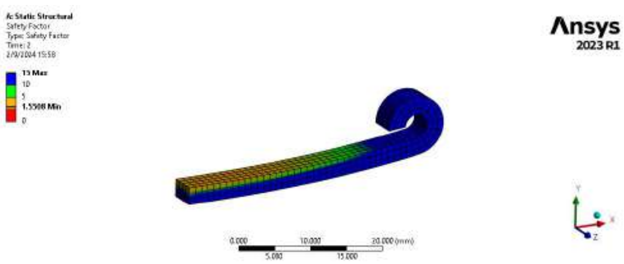

Fig. 7 Factor of safety

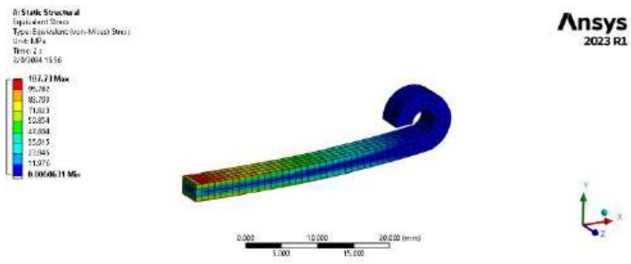

Fig. 8 Equivalent von-mises stress

TABLE V- RESULTS OBTAINED

Load (N)	Analytical		Software simulation	
	Stress (N/mm^2)	Deflection (mm)	Stress (N/mm^2)	Deflection (mm)
24	100.8	1.122	98.35	0.9398
25	105	1.169	107.73	0.9598
26	109.2	1.216	112.04	0.9982
27	113.4	1.262	116.55	1.0367

28	117.6	1.309	120.66	1.075
29	121.8	1.356	124.97	1.1134
30	126	1.403	129.27	1.1518

B. Wheel

The structural integrity of the wheel design was thoroughly examined through a static structural analysis using ANSYS, facilitating a comprehensive evaluation of its performance under loading conditions, including stress distribution, deformation, and other critical parameters. By conducting static structural analysis, we gained detailed insights into how the wheel responds to loading scenarios. The wheel model was carefully meshed with a 2mm mesh size in ANSYS as shown in Fig. 9, ensuring precise representation of geometry, and capturing structural behavior (Fig. 14) with sufficient accuracy to assess stress distribution, deformations, and other relevant mechanical responses. The analysis enabled evaluation of stress distribution, deformation, and safety factor, contributing significantly to the overall assessment of the wheel's performance. Fig. 9 to 14 depict wheel simulation under loading conditions, illustrating equivalent von mises stress and the factor of safety.

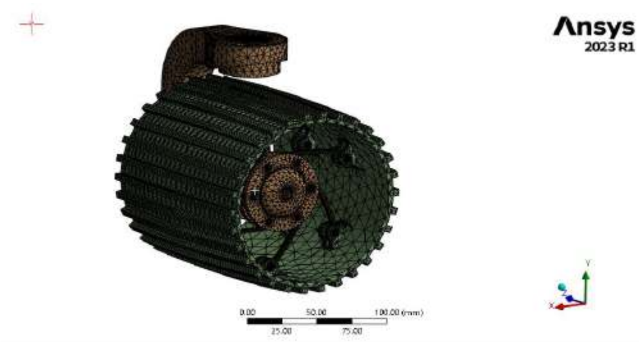

Fig. 9 Meshing of the wheel

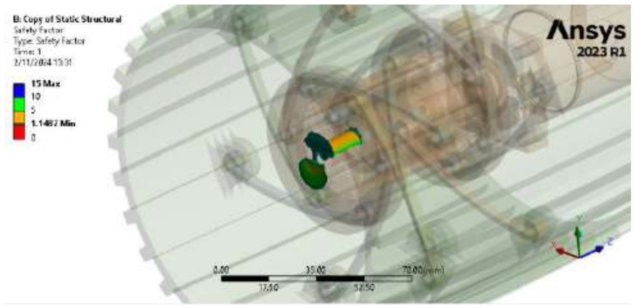

Fig. 10 Factor of safety

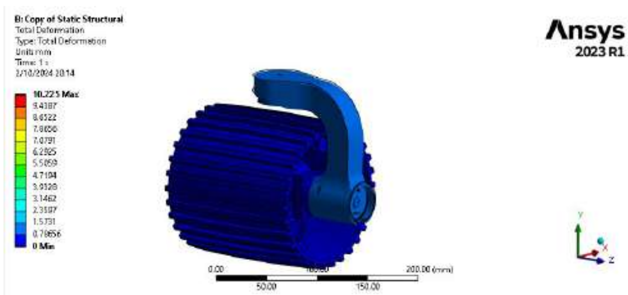

Fig. 11 Deformation

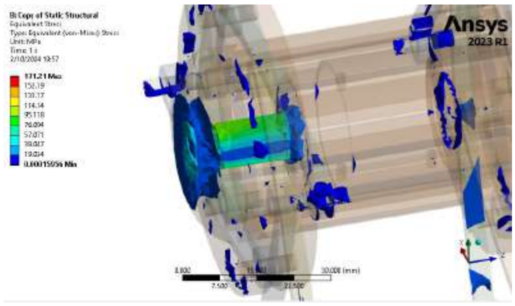

Fig. 12 Equivalent von-mises stress

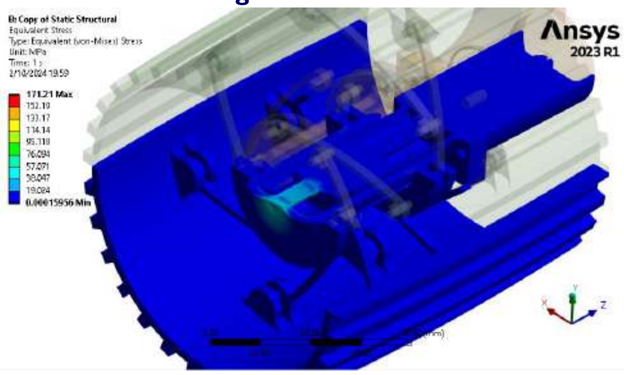

Fig. 13 Equivalent von-mises stress

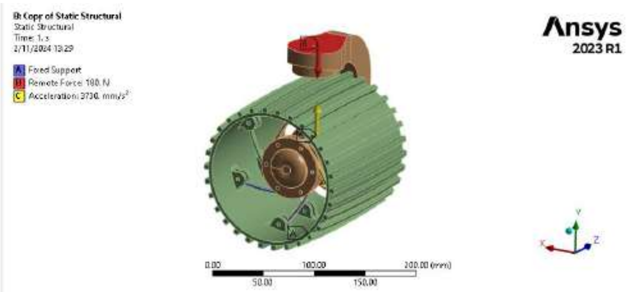

Fig. 14 Static structural

VII. CONCLUSION

This paper presents a simplified approach to understanding the design and analysis of Mars rover wheels, contributing to advancements in planetary exploration. Through research and simulations, we have developed a durable wheel design that enhances traction and optimizes weight. The utilization of magnesium R5 alloy for the leaf spring material demonstrates its potential as a favourable choice. Simulation results indicate a close alignment between analytical and simulated outcomes, affirming the suitability of this material. While our findings aid space agencies in improving rover mobility, more research is needed for areas like wheel damage prevention and advanced navigation algorithms.

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