Section-B: Designing and Modeling
(C) Wheel

1. **Design a CAD model of wheel with proper material that can efficiently handle the challenges of Mars-like terrain in ERC and URC. Explain how your design ensures stability, traction, and adaptability.**

1. Wheel Structure

- Spokes and Rim: The wheel will have a spoked structure to minimize weight while maintaining strength. The spokes will be arranged in a way that provides rigidity without adding too much bulk, ensuring the wheel can withstand the impact from rocks and rough terrain. The rim will be designed to be wide enough to prevent the wheel from sinking into soft soil but also provide adequate support for high-speed challenges in the URC.
- Material: The wheel will be made of aluminum alloy (such as 6061-T6), which provides a good balance of lightweight properties and strength, making it ideal for handling both Martian terrains and the high-speed challenges of the URC. Aluminum is also resistant to corrosion and has good thermal properties for temperature fluctuations on Mars.

2. Tire Design

- Tread Pattern: A non-aggressive tread pattern will be used to enhance traction on soft and rocky surfaces. The tire will have multiple deep grooves to grip into fine dust and loose regolith, preventing sinking. At the same time, the tread will be shallow enough to provide stable movement over hard rocky surfaces.
- Material: The tire will be made of SBR (Styrene-Butadiene Rubber), a durable material commonly used in engineering applications. It is resilient to abrasion and has good wear resistance, ensuring that the tire maintains its functionality over time, even in the abrasive Martian environment.

3. Adaptability and Flexibility

- Suspension: The wheel will be part of a suspension system that allows some flexibility to adjust to the terrain. This ensures that the wheel maintains contact with the surface and absorbs shocks from rocky obstacles.
- Adjustable Pressure: The tire may be designed to handle variable air pressure, allowing it to adapt to different terrains by inflating or deflating based on the environment.

4. Manufacturability

- The materials chosen (aluminum and SBR) are both widely available and easy to fabricate, which is crucial for both practical rover deployment and simulation in competitions like the ERC and URC.

2. **How do different wheel structures (solid, flexible, or mesh) impact performance in low-gravity and high-friction environments? Which type would be most effective for a Mars mission? Justify.**

The performance of a wheel in a low-gravity, high-friction environment like Mars is influenced by its structure. Below is an analysis of three common types: solid, flexible, and mesh wheels.

1. Solid Wheels

Impact on Performance:

- **Advantages:**
  - Extremely durable and resistant to punctures or wear from sharp rocks.
  - Simple design with no moving parts, reducing failure points.
  - Provides good load-bearing capacity.
- **Disadvantages:**
  - Poor adaptability to uneven surfaces—lacks the ability to deform for increased contact area.
  - Can lead to excessive bouncing or loss of contact due to the lack of shock absorption.
  - Heavy, which increases energy consumption in a low-gravity environment.

Use Case:

- Best for high-load applications where durability is critical and terrain is relatively firm.

2. Flexible Wheels (Spring-Based or Elastic Structures)

Impact on Performance:

- **Advantages:**
  - Can deform to increase the contact patch, enhancing traction on loose soil.
  - Absorbs shocks effectively, reducing vibrations that could damage the rover.
  - Lighter than solid wheels, reducing energy consumption in low gravity.
- **Disadvantages:**

    - Potential for mechanical fatigue over time, especially under extreme temperature variations.
    - More complex construction, requiring additional engineering considerations.

Use Case:

- Suitable for rough and uneven terrains, where shock absorption and adaptability are crucial.

3. Mesh Wheels (Metallic or Fabric Mesh)

Impact on Performance:

- **Advantages:**
    - Lightweight, reducing energy consumption in low gravity.
    - Deformable structure conforms to irregular surfaces, enhancing traction and preventing excessive sinking.
    - Self-cleaning ability, dust and debris do not easily accumulate, which is critical in Mars' dusty environment.
- **Disadvantages:**
    - Susceptible to damage from sharp rocks if the mesh is not reinforced properly.
    - May require specialized materials like shape-memory alloys for long-term resilience.

Use Case:

- Ideal for soft soil and rocky terrains, where adaptability and self-cleaning properties are required.
- NASA's Curiosity and Perseverance rovers use a variation of mesh wheels with metal treads for Mars exploration.

Most Effective Type for a Mars Mission

Given Mars' low gravity (~38% of Earth's) and challenging terrain (soft regolith, rocky outcrops, and fine dust), the most effective wheel design would be a hybrid of flexible and mesh wheels. Research on shape memory alloy wheels for Mars missions discusses the advantages of mesh designs in supporting high loads while adapting to surface variations, making them suitable for Mars' terrain.

Justification:

- **Weight Efficiency:** Mesh or flexible wheels reduce weight compared to solid wheels, which is crucial for optimizing the rover's energy usage.

- **Traction and Adaptability:** Flexible or mesh structures allow deformation, improving traction in soft soil and on rocky surfaces.
- **Durability and Longevity:** Solid wheels wear out quickly on abrasive Martian soil, while mesh wheels have been proven effective in past missions (Curiosity, Perseverance).
- **Dust Resistance:** A mesh or open-structure wheel prevents excessive dust accumulation, which is a major issue on Mars.

Material Selection:

- Aluminium alloy 6061 T-6 for shaft and outer part.
- SBR for tire.

A spoked wheel made of Aluminium alloy with an SBR tire is a smart choice because it provides:

- A lightweight, rigid structure for efficient mobility.
- Shock absorption and traction from the SBR rubber.
- Customizable tread patterns to handle different terrains effectively.

Conclusion:
A hybrid flexible-mesh or spoked wheel would be the most effective choice for a Mars mission, ensuring durability, adaptability, and energy efficiency while maintaining traction on unpredictable surfaces.

References:

1. https://www.sciencedirect.com/science/article/abs/pii/S009457652030374X
2. https://ntrs.nasa.gov/api/citations/20100000019/downloads/20100000019.pdf
3. https://www.leorover.tech/post/different-shades-of-wheel
4. https://science.nasa.gov/mission/mars-2020-perseverance/rover-components
5. https://journals.sagepub.com/doi/10.1177/09544062221126630
6. https://www.theseus.fi/bitstream/10024/503368/3/Zambelli_Giovanni.pdf
7. https://www.researchgate.net/publication/382641578_Design_and_Analysis_of_Mars_Rover_Wheel
8. https://www.researchgate.net/publication/325630398_Traction_Control_Design_and_Integration_Onboard_the_Mars_Science_Laboratory_Curiosity_Rover
9. https://www.researchgate.net/publication/335425252_Terrain-adaptive_wheel_speed_control_on_the_Curiosity_Mars_rover_Algorithm_and_flight_results
10. https://www.researchgate.net/publication/377901862_Design_and_Simulation_of_a_Four-Wheeled_Rover_for_Enhanced_Lateral_Stability
11. https://www.researchgate.net/publication/220122340_Stability_and_Traction_Optimization_of_a_Reconfigurable_Wheel-Legged_Robot
12. https://www.researchgate.net/publication/286491921_Increasing_the_mobility_of_Mars_rovers_by_improving_the_locomotion_systems_and_their_control_algorithms

13. https://www.researchgate.net/publication/271190621_Design_Optimization_of_a_Mars_Rover%27s_Rocker-Bogie_Mechanism_using_Genetic_Algorithms
14. https://www.researchgate.net/publication/362801668_Conceptual_Study_on_Materials_Selection_for_Martian_Rover
15. https://www.researchgate.net/publication/336185520_Parametric_study_and_design_guidelines_for_rigid_wheels_for_planetary_rovers
16. https://www.researchgate.net/publication/327808218_Wheel_Design_Methodology_for_a_Lunar_Exploration_Rover_in_Order_to_Improve_Trafficability_Considering_Operation_Environment