ENAE788X - PLANETARY SURFACE ROBOT

LUNAR LIGHT UTILITY VEHICLE

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INTRODUCTION

The Lunar Light Utility Vehicle (LLUV) project represents a critical advancement in lunar surface operations. This specialized rover is conceived as a smaller, more agile counterpart to the lunar terrain vehicle (LTV), focusing on essential utility tasks around lunar bases rather than human transport.

Key aspects of the LLUV:

- Autonomous and teleoperated capabilities from multiple control points (lunar surface, lunar orbit, or Earth)
- Specialized for site preparation, light assembly, and infrastructure support
- Integration with Commercial Lunar Payload Services (CLPS) landers
- Adaptable design with potential Mars application considerations

PROJECT REQUIREMENTS

Mass and Dimensional Constraints

- Maximum operational mass: 500 kg with 30% margin
- Must be compatible with CLPS lander dimensions
- Self-contained capability to drive off lander

Mobility Performance

- Maximum velocity: 3 m/sec (without external payload)
- Obstacle clearance: Minimum 30 cm height
- Payload capacity: 1000 kg (transport and lifting)
- Terrain adaptability: Suitable for lunar south pole conditions

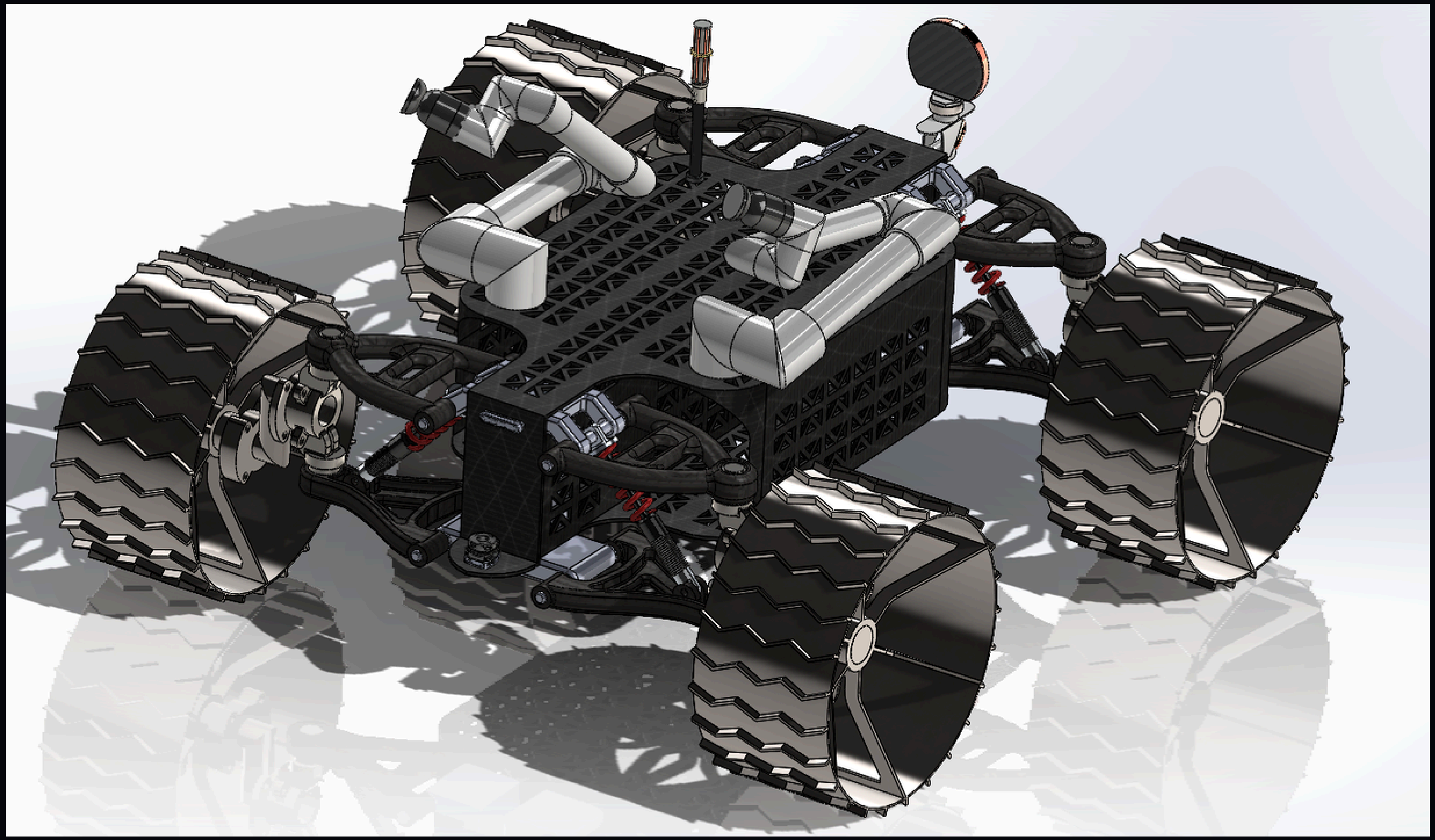
Power and Operation

- Battery-powered system for 8-hour operation with 20% margin
- Self-connecting capability to provided recharger
- Autonomous power management and recharging systems

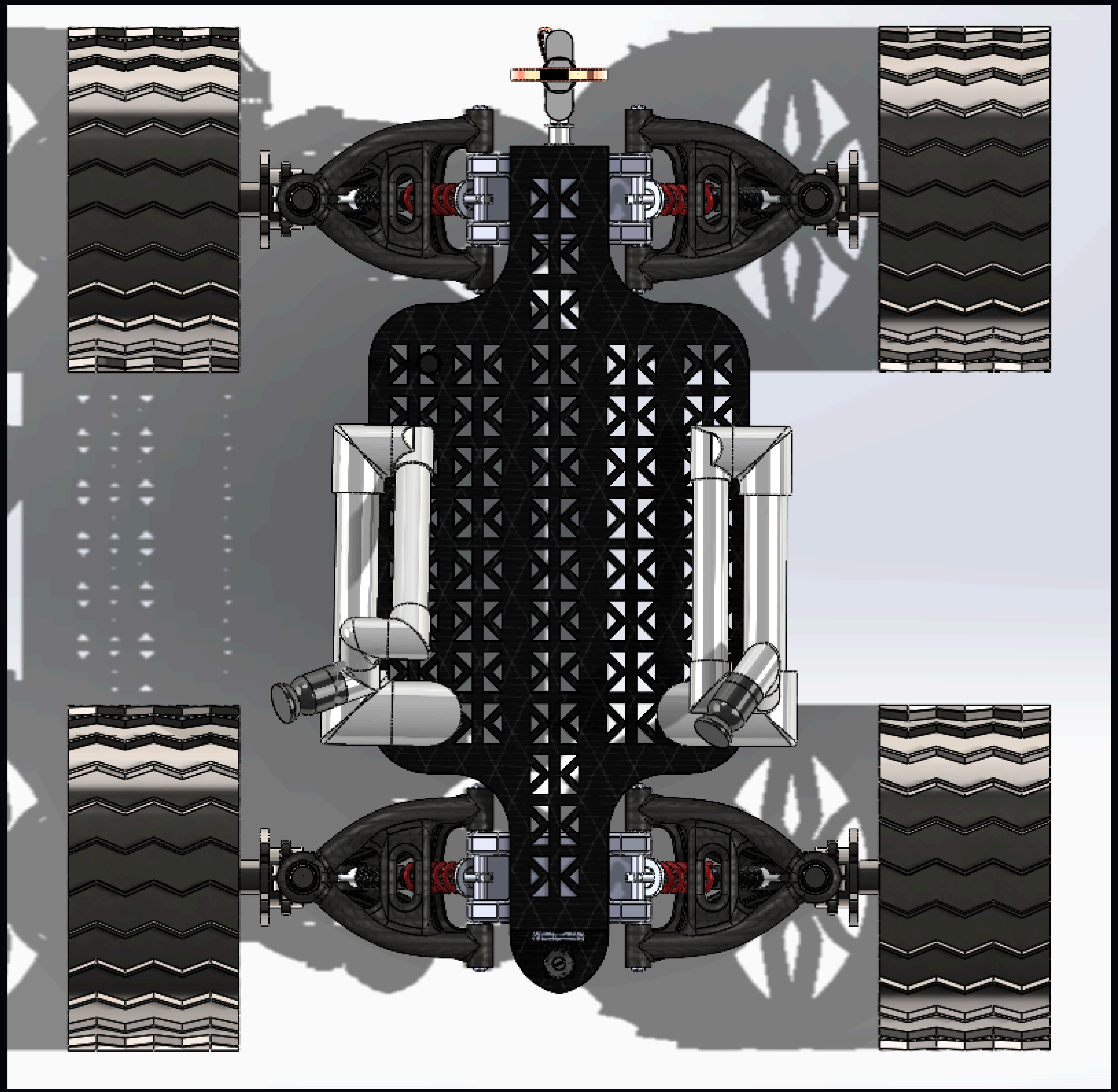
Functional Requirements

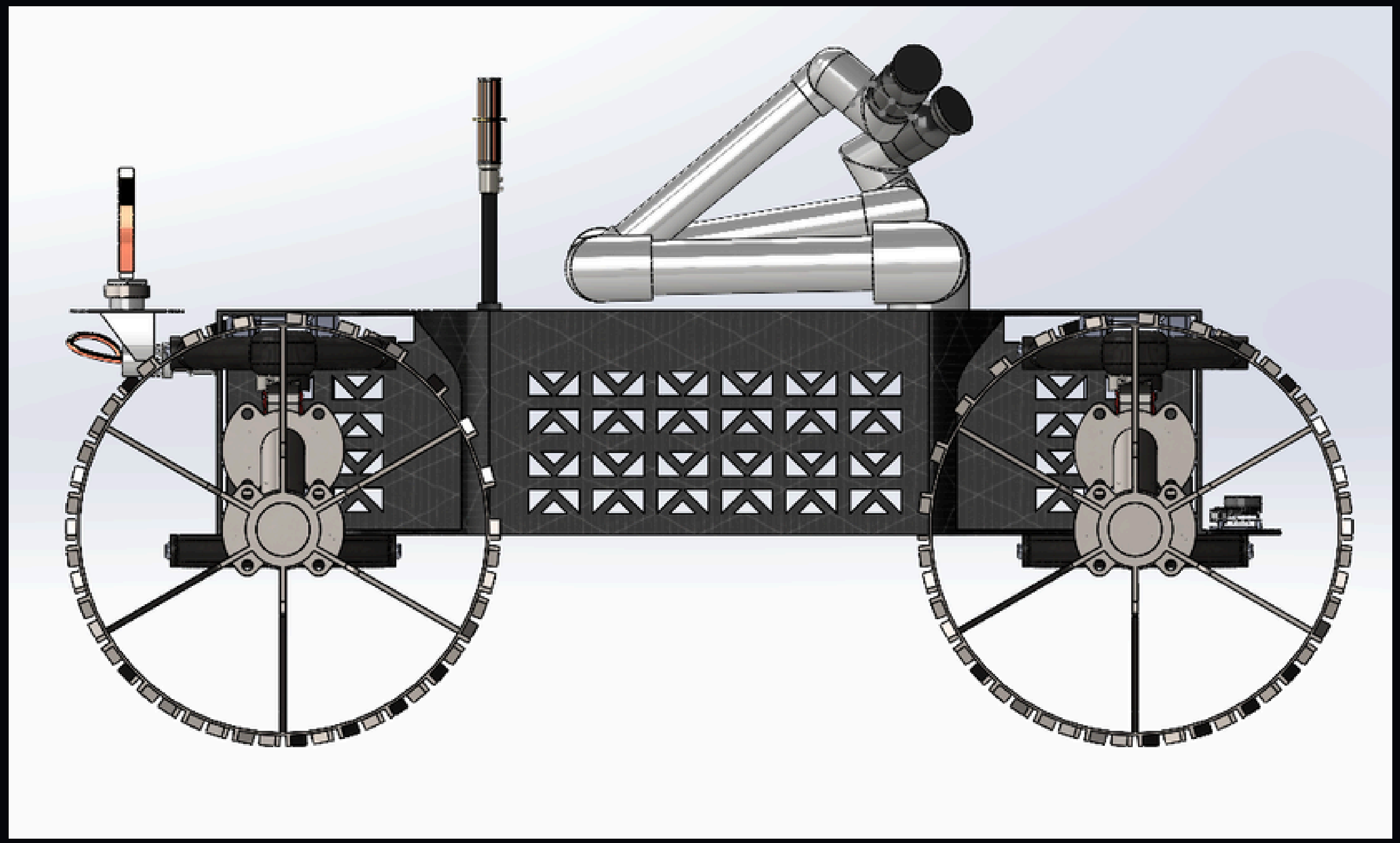
- Robotic systems capable of performing mechanical connections, managing electrical interfaces, handling fluid connections, and modifying surface contours around the lunar base.
- Autonomous operation capability and teleoperation interfaces that can be controlled from three locations - lunar surface, lunar orbit, or Earth.

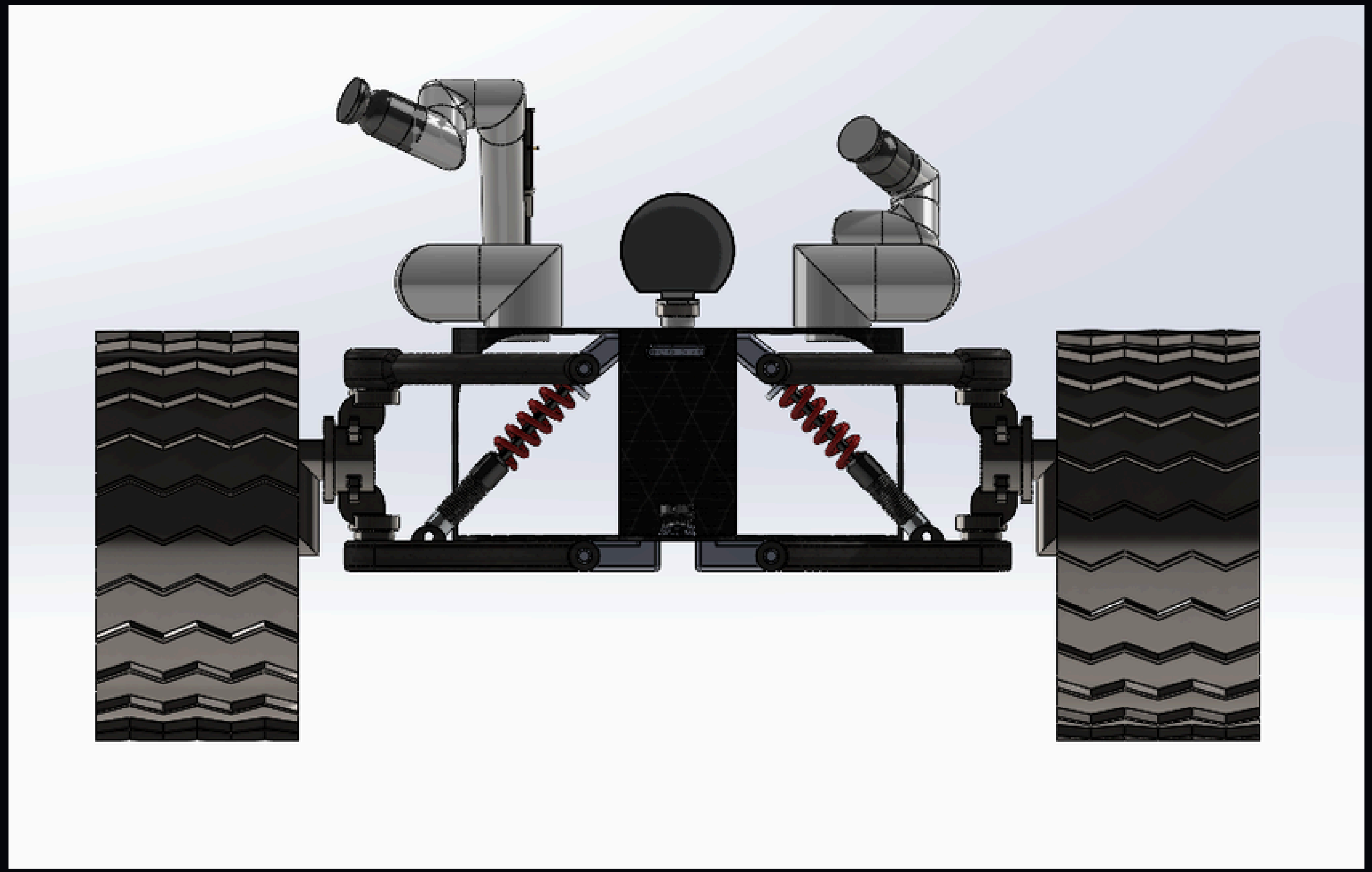
ROVER DESIGN



ROVER DESIGN

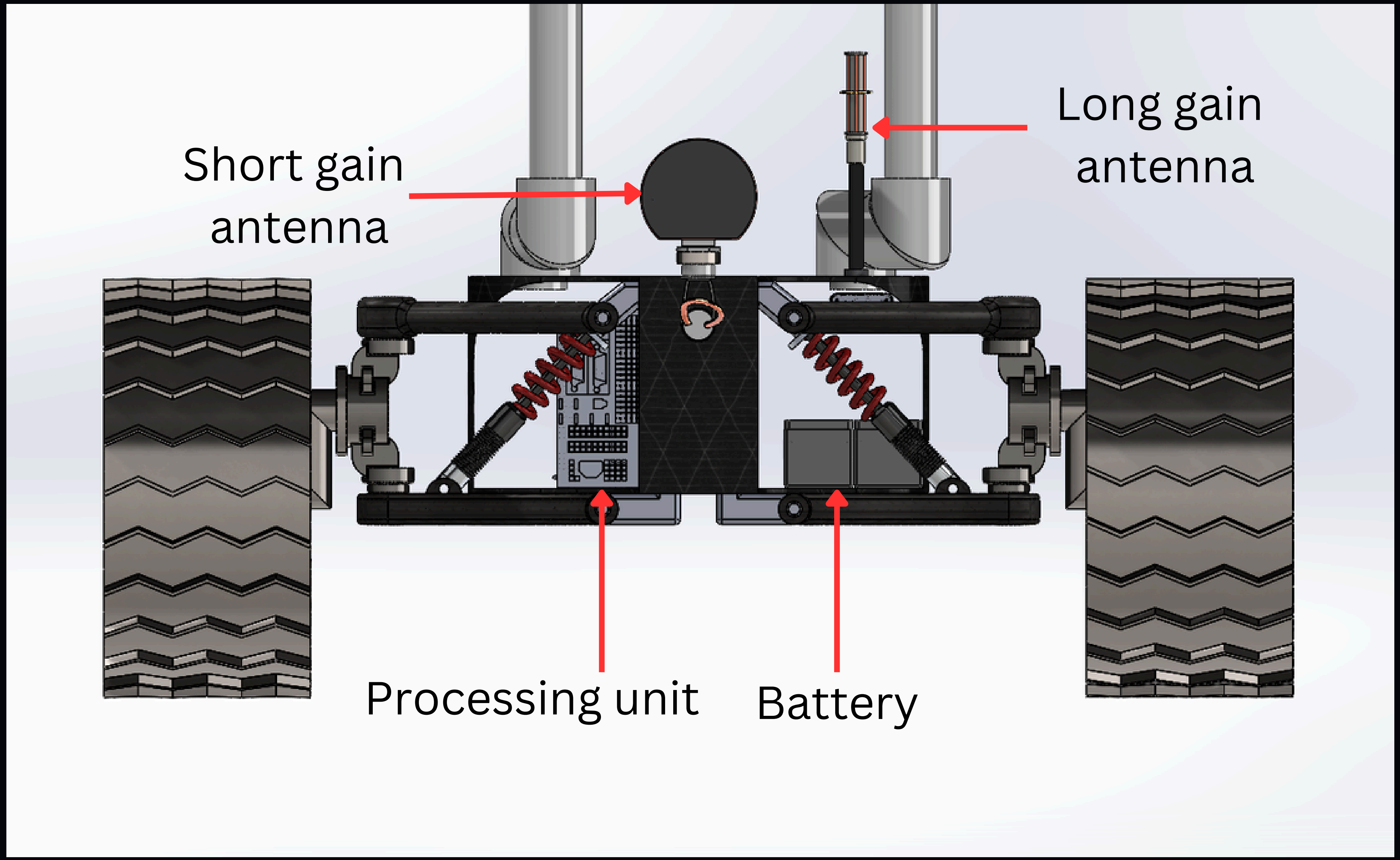




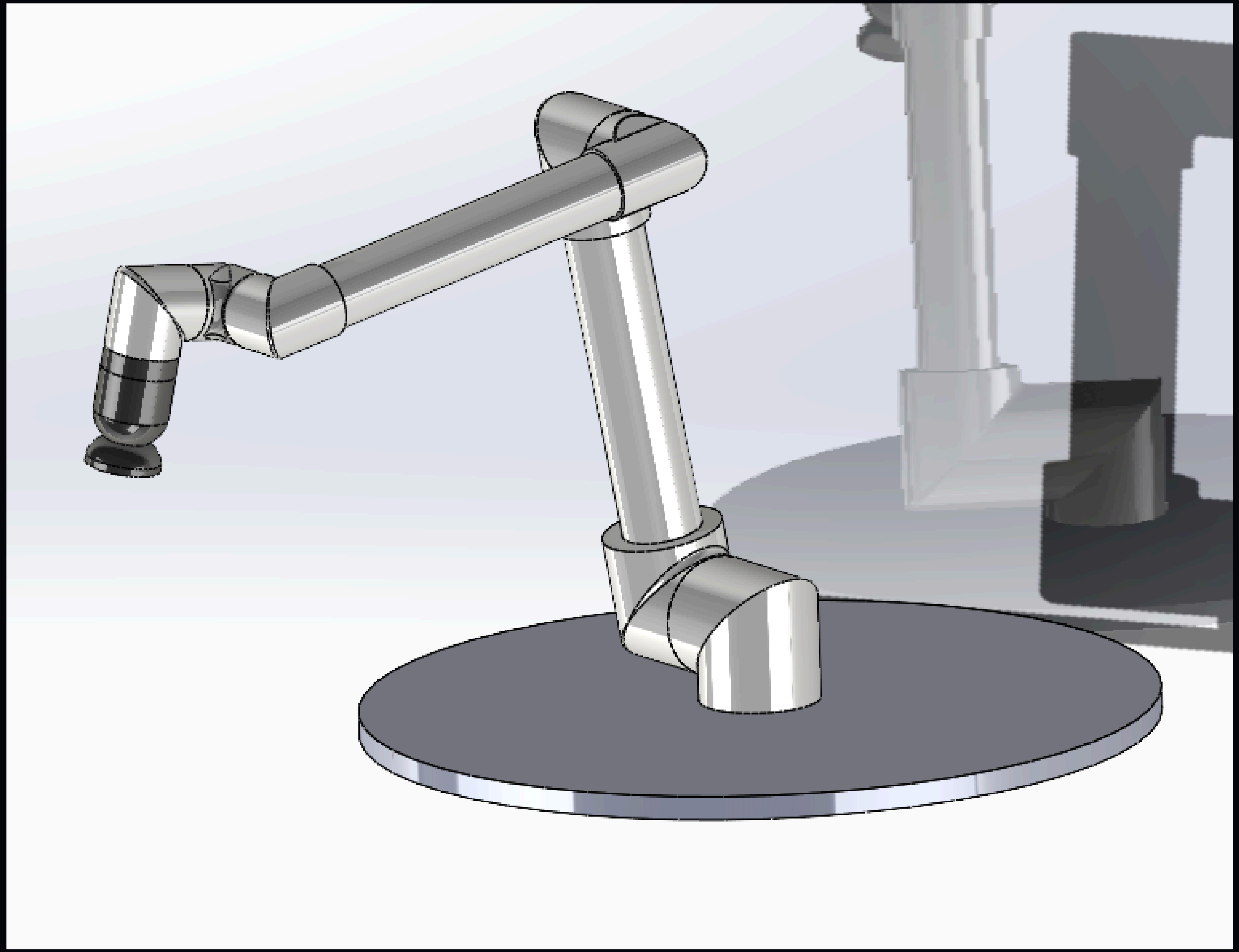


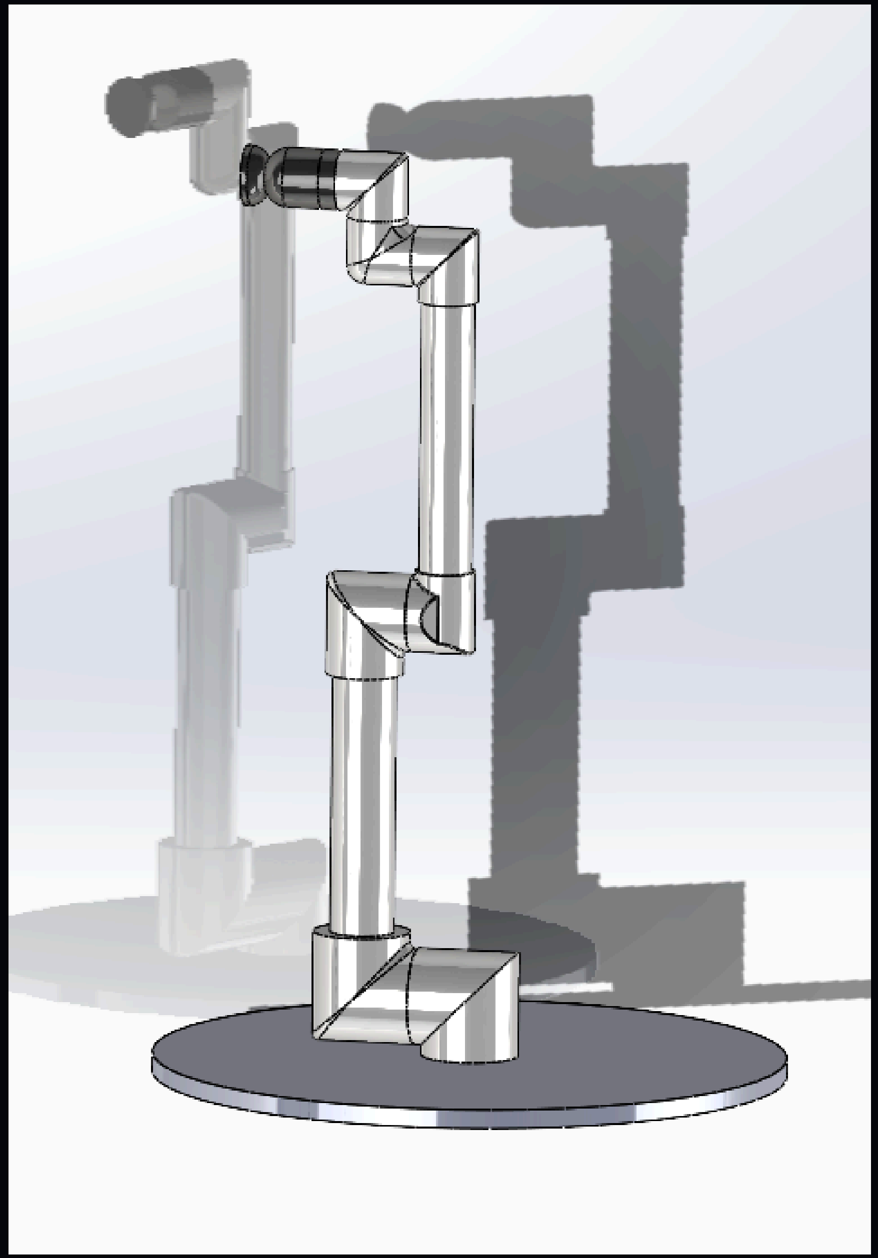
ROVER DESIGN

Over here we can see the robot has a battery and computer component and it aslo has long gain antenna and short gain antenna

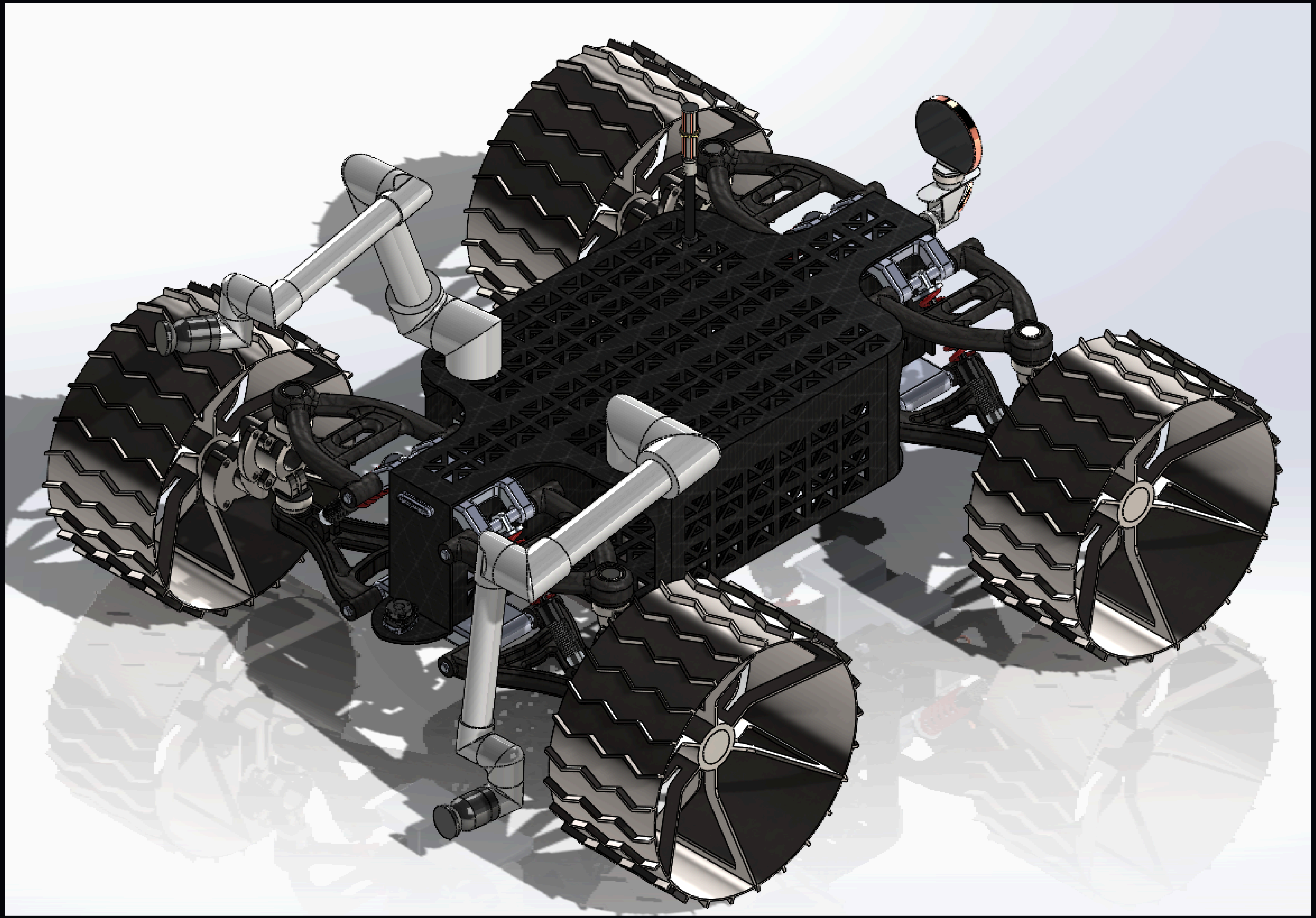


ROBOT ARMS



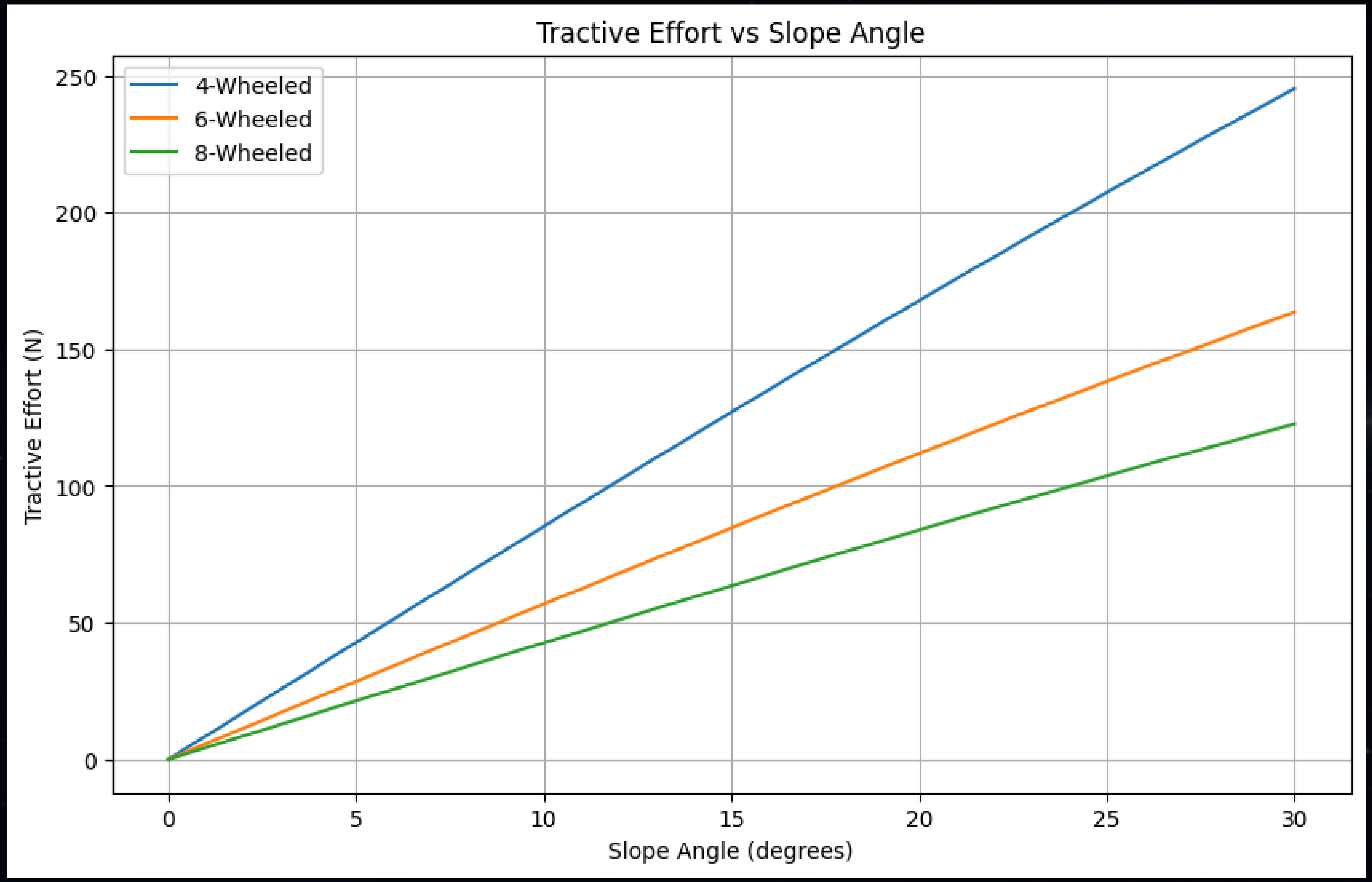


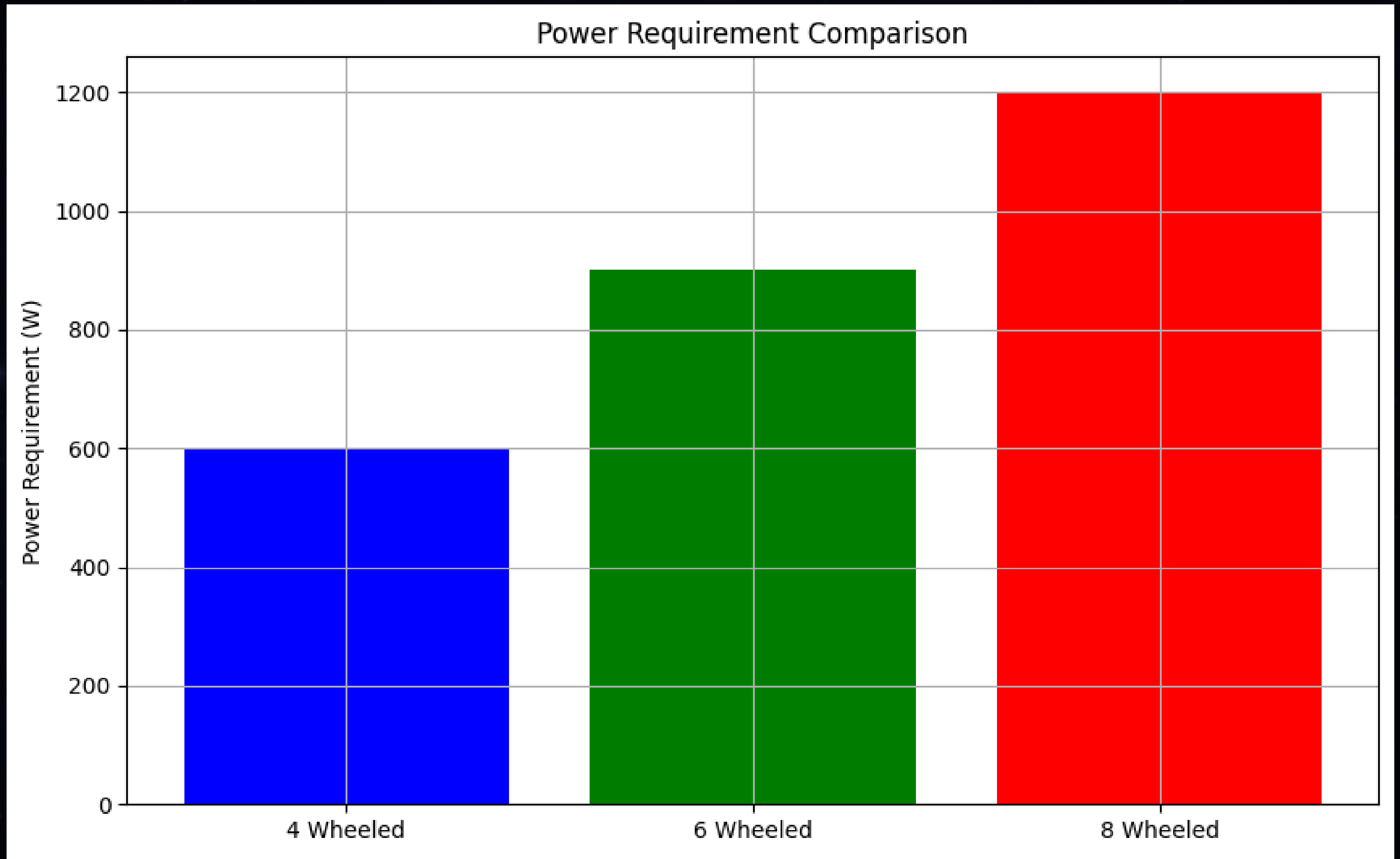
ARMS EXTENDED



WHEEL DESIGN

Trade Study to decide number of wheels

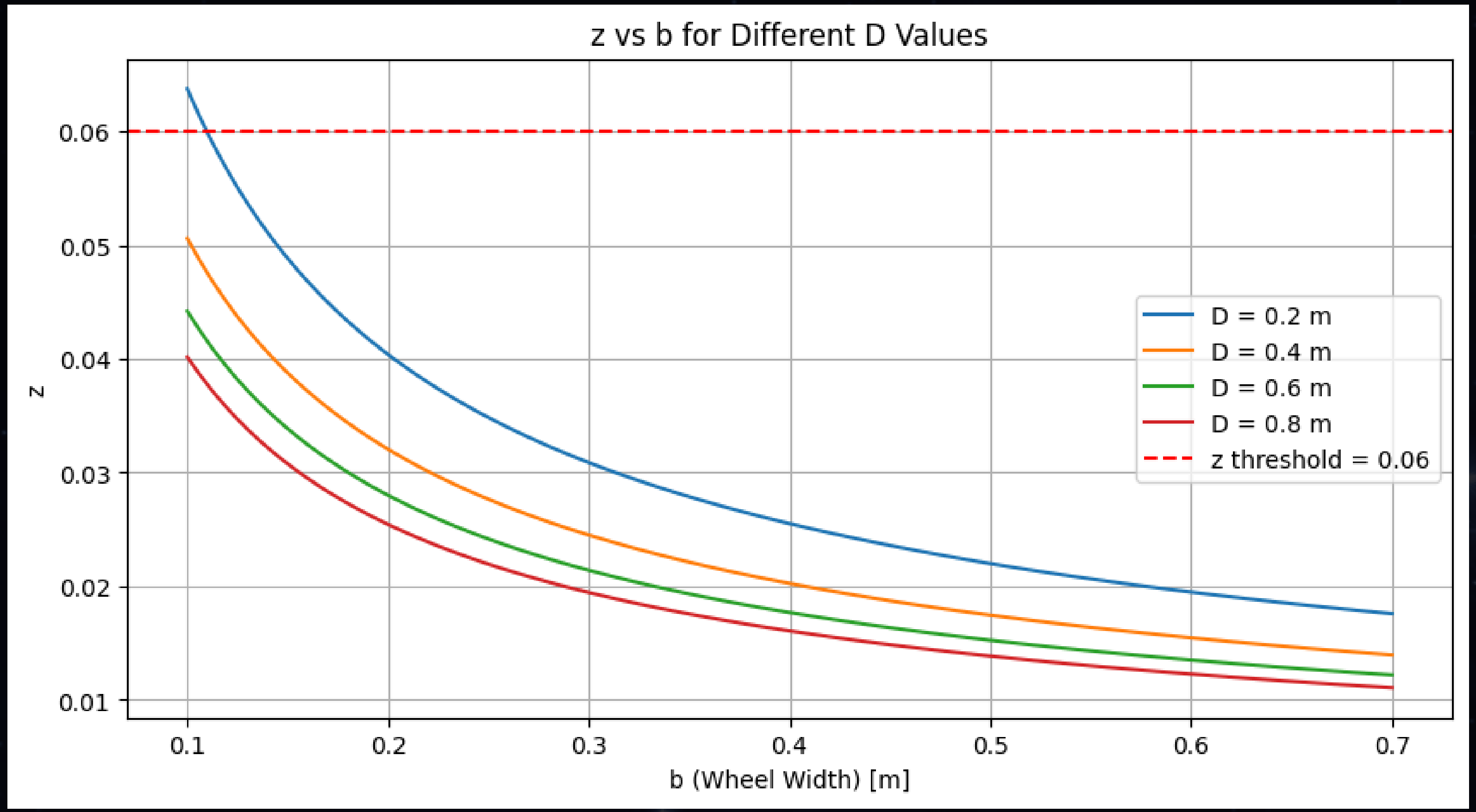


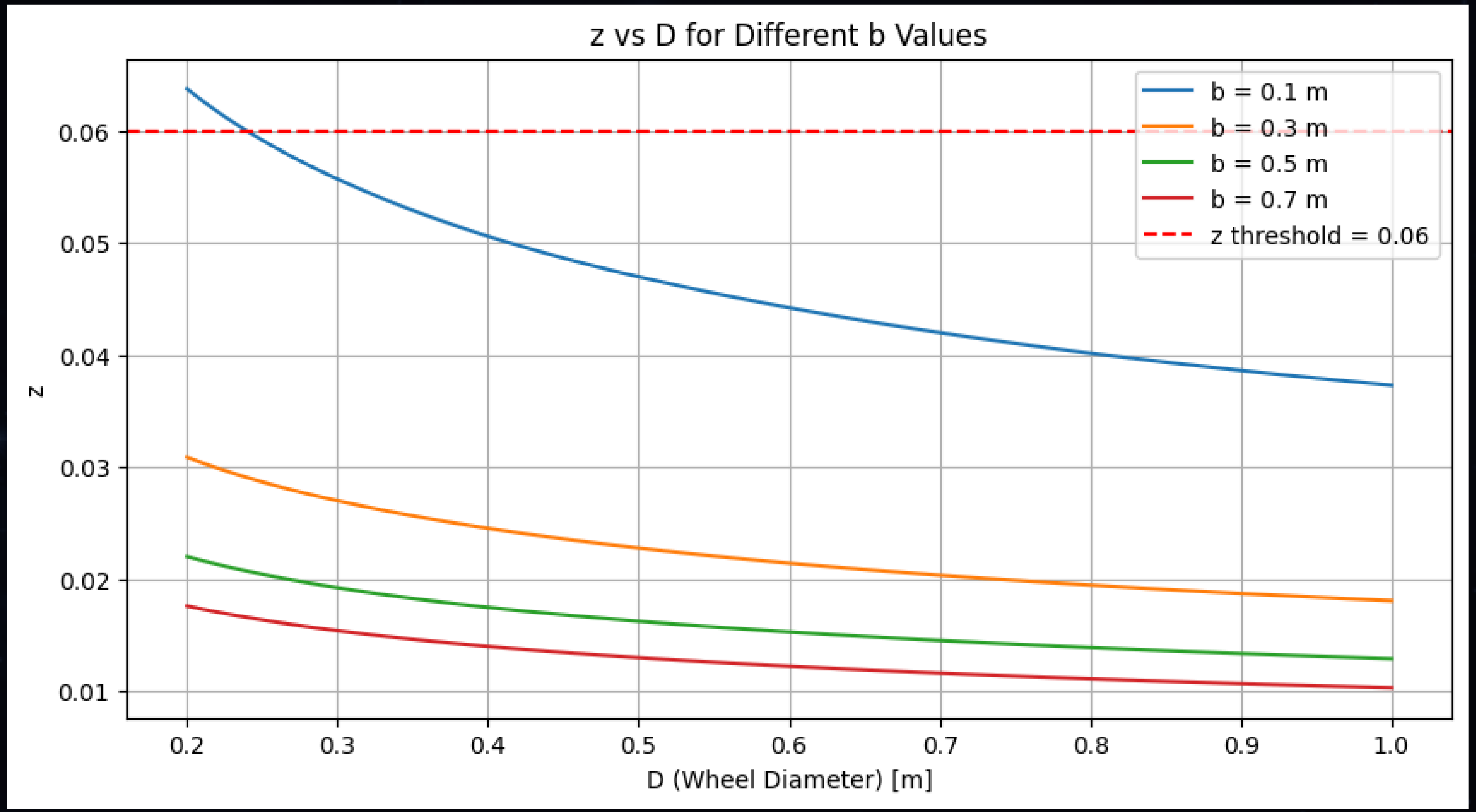


Based on the power and mass constraints, 4 wheel system is considered to be efficient for our project requirements.

WHEEL DESIGN

Analysis to find optimal values of b and D





Calculated the sinkage (z) for various combinations of wheel width and diameter values.

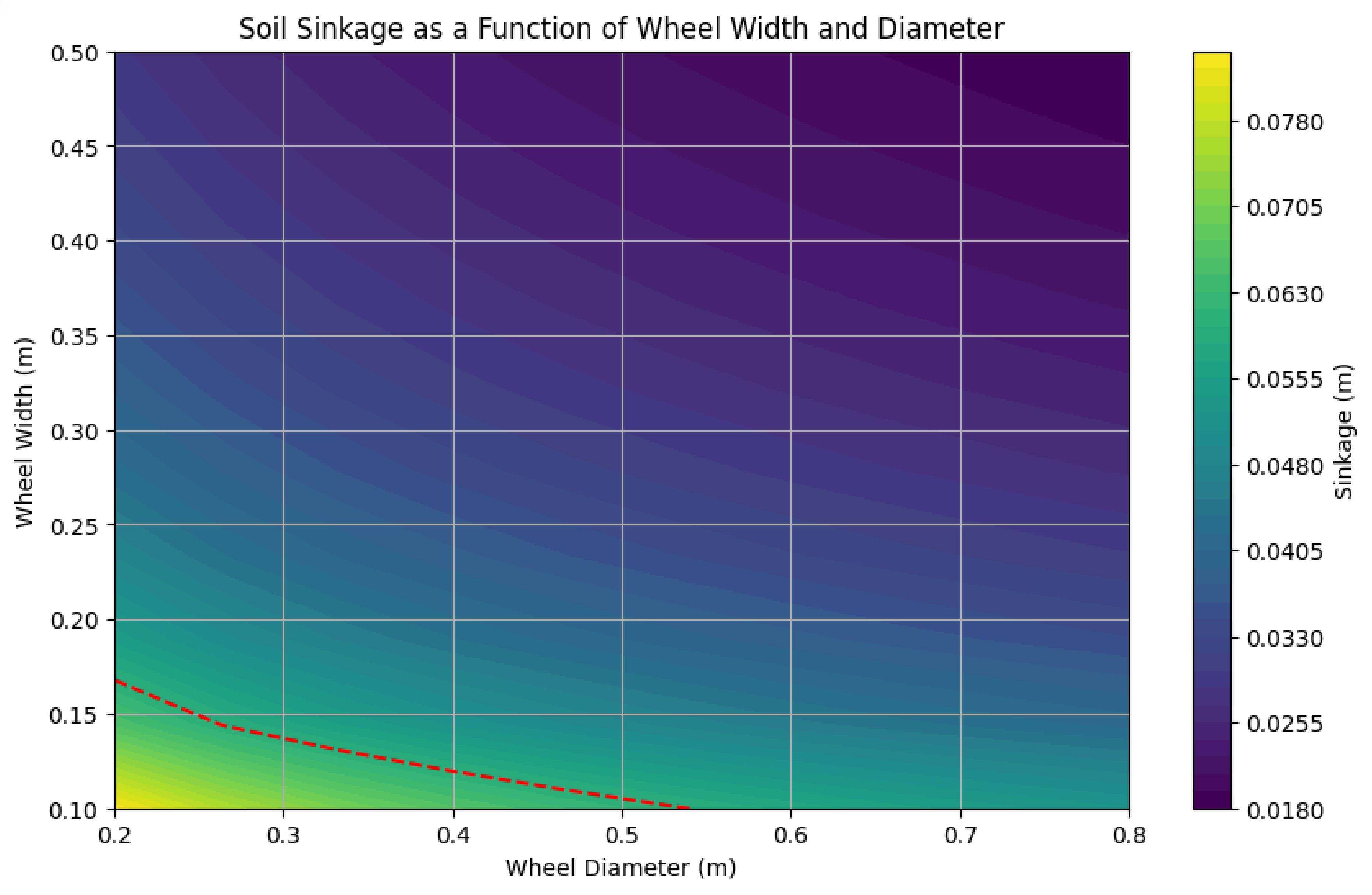
Chose an optimal value to provide a balance between minimizing wheel dimensions while maintaining adequate ground clearance and soil interaction.

WHEEL DESIGN

$$z = \left(\frac{3 \cdot W_w}{(3-n) \cdot (k_c + b \cdot k_\phi)\sqrt{D}} \right)^{\frac{2}{2n+1}}$$

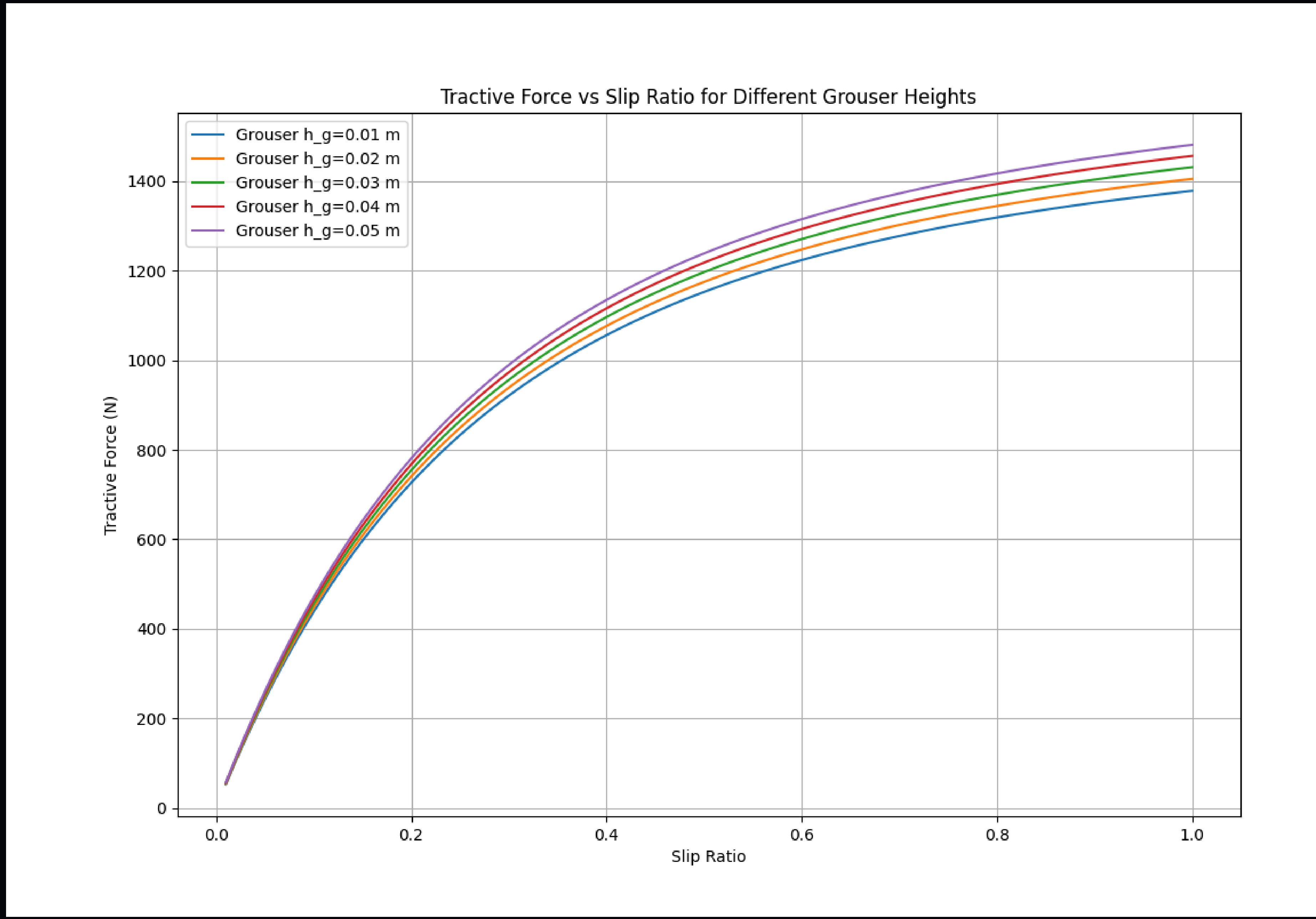
where:

$$W_w = 607.5\text{N}(\text{weight per wheel})$$
$$k_c = 1400\text{N/m}^2(\text{cohesive modulus})$$
$$k_\phi = 830000\text{N/m}^3(\text{frictional modulus})$$
$$b = \text{wheel width}(\text{m})$$
$$D = \text{wheel diameter}(\text{m})$$
$$n = 1(\text{soil constant})$$



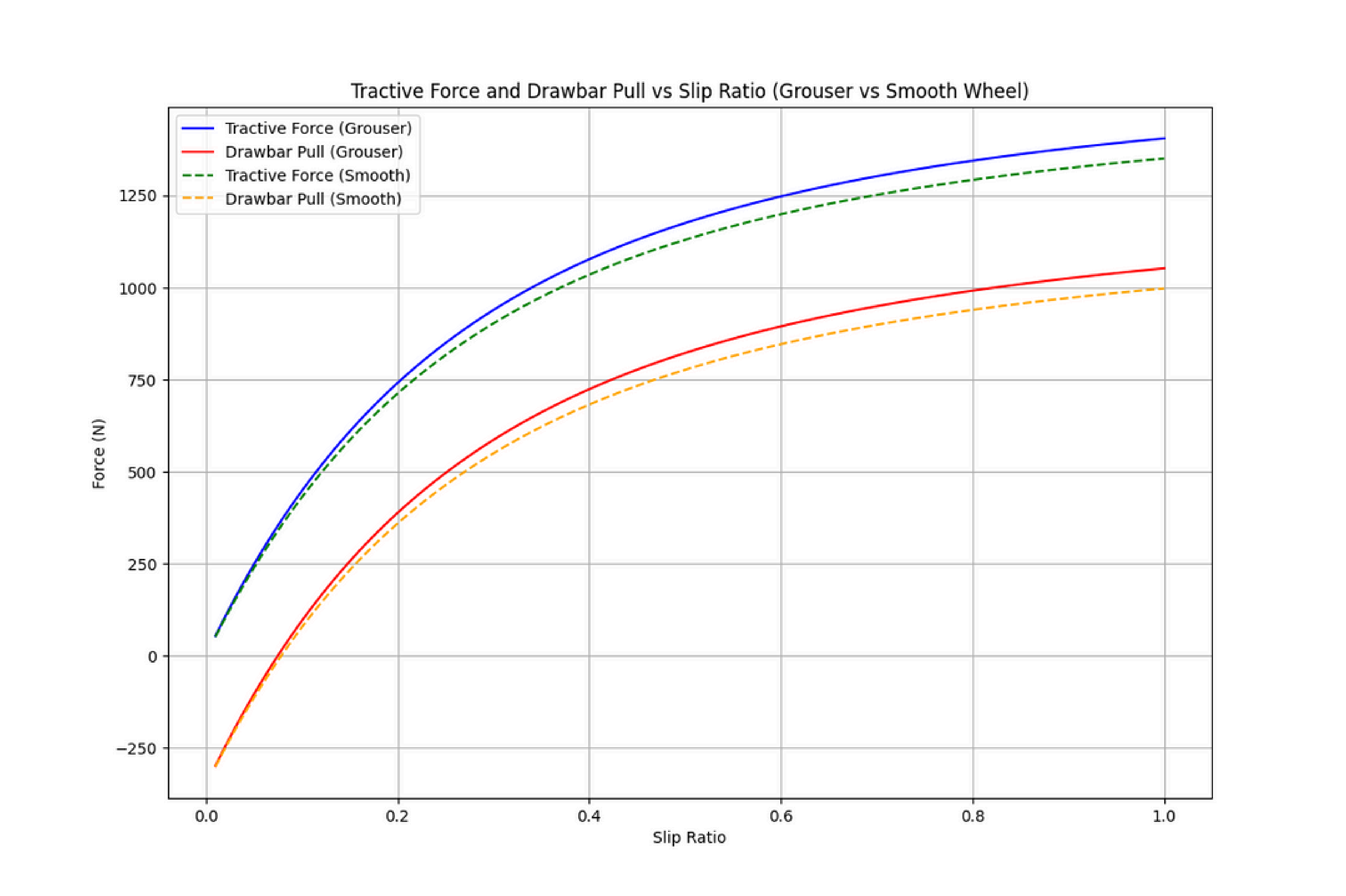
Optimal value of b and D that satisfy z <= threshold:
Wheel Width (b) = 0.4 m, Wheel Diameter (D) = 0.77m, Resulting z = 0.0213m = 2.13cm

SELECTING GROUSER HEIGHT



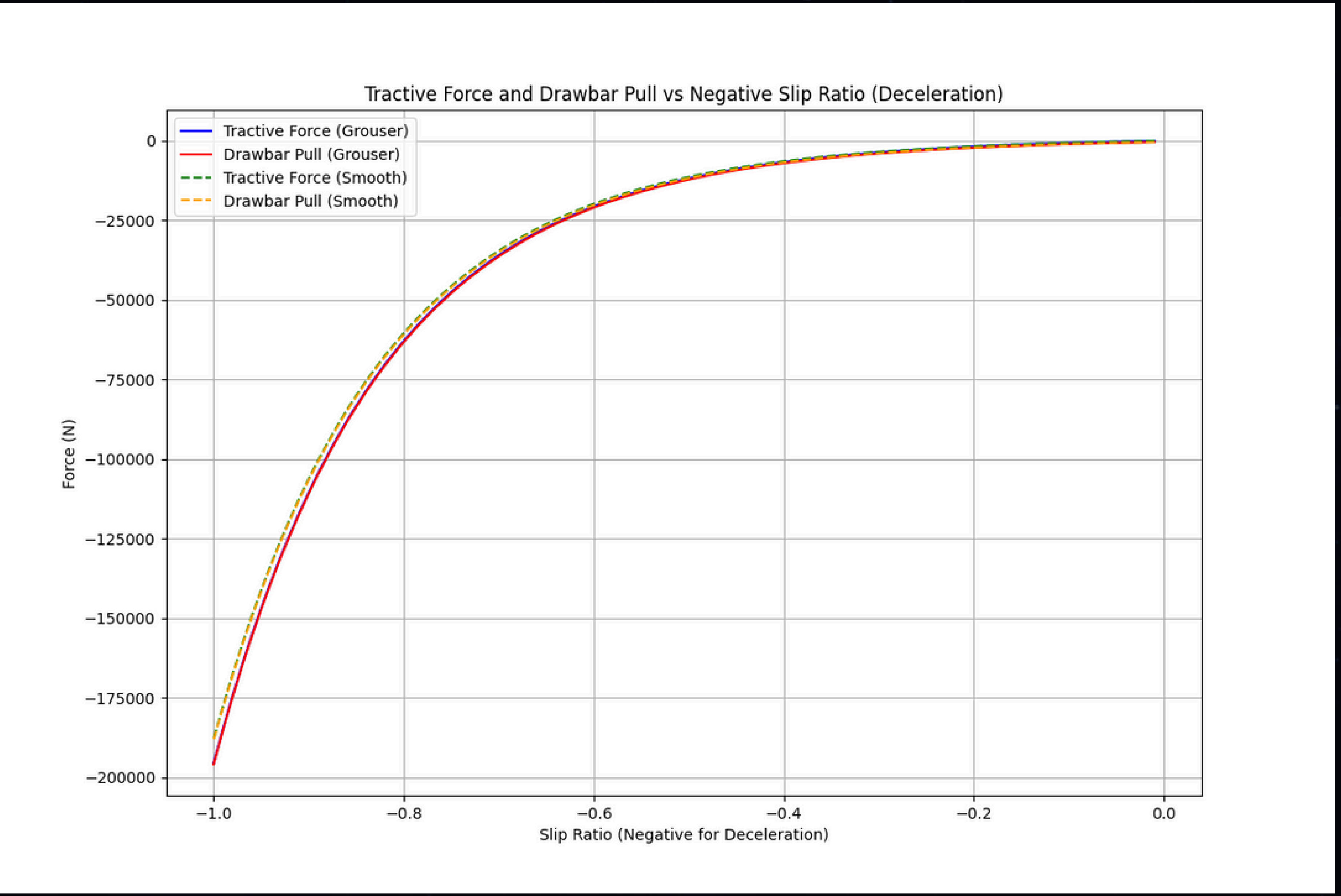
- Influence of Grouser Height: Increasing grouser height consistently increases the tractive force at every slip ratio, indicating that taller grousers can provide better traction on soft lunar terrain.
- Enhanced Performance with Slip: As the slip ratio grows, the difference in tractive force between lower and higher grouser heights becomes more pronounced, showing that taller grousers maintain higher levels of force even under more significant slippage.
- Tailoring Wheel Design: By adjusting the grouser height, we can optimize wheel-soil interaction. Taller grousers may be beneficial for harsher soil conditions, while shorter grousers could balance performance and manufacturing constraints.
- Design Trade-offs: While increased grouser height improves traction, it may also add complexity or weight. These results help guide decisions on how much grouser height to incorporate for optimal vehicle mobility.

DRAW BAR PULL - GROUSERS VS SMOOTH



- Comparing Grouser vs. Smooth Wheels: Grousers deliver higher tractive force and drawbar pull at any given slip ratio.
- Increasing Slip Ratio: Both tractive force and drawbar pull rise as the wheel slip increases, but grousers outperform smooth wheels throughout.
- Terrain Adaptation: Grousers are more effective on soft or loose soils, providing improved grip and load-pulling capability.
- Design Implication: Selecting a wheel type (grouser vs. smooth) directly affects the vehicle's ability to handle slippage and maintain traction under lunar conditions.
- Grouser height = 0.02

DRAW BAR PULL - DECELERATION



- Deceleration Dynamics: Negative slip ratio represents braking or slowing conditions, showing how forces behave as the wheel rotation slows relative to the vehicle's forward speed.
- Grousers vs. Smooth in Braking: Grousers still provide a higher absolute force under deceleration, which mean better braking performance and control on loose lunar soil compared to smooth wheels.
- Higher Negative Slip, Greater Negative Force: As slip ratio decreases (more negative), the net force can become increasingly negative, indicating stronger braking or resisting forces.
- Practical Takeaway: Understanding these forces during deceleration helps in selecting wheel designs and controlling braking systems to maintain stability and safety on lunar terrain.

Rolling Resistance

No Payload, slope 0 Degree

```
Rb: 112.56055289016089
Rc: 27.852100877895992
Rr: 10.125
Rg: 0.0
Total Rolling Resistance: 346.65450929190575
Rolling Resistance per wheel: 86.66362732297644
```

1000Kg Payload, slope 0 Degree

```
Rb: 202.0434667996069
Rc: 120.50904156991223
Rr: 30.375
Rg: 0.0
Total Rolling Resistance: 916.4980998788627
Rolling Resistance per wheel: 229.12452496971568
```

No Payload, Slope 25 Degrees

```
Rb: 112.56055289016089
Rc: 27.852100877895992
Rr: 10.125
Rg: 85.58019800249164
Total Rolling Resistance: 432.23470729439737
Rolling Resistance per wheel: 108.05867682359934
```

1000Kg Payload, Slope 25 Degrees

```
Rb: 202.0434667996069
Rc: 120.50904156991223
Rr: 30.375
Rg: 256.7405940074749
Total Rolling Resistance: 1173.2386938863376
Rolling Resistance per wheel: 293.3096734715844
```

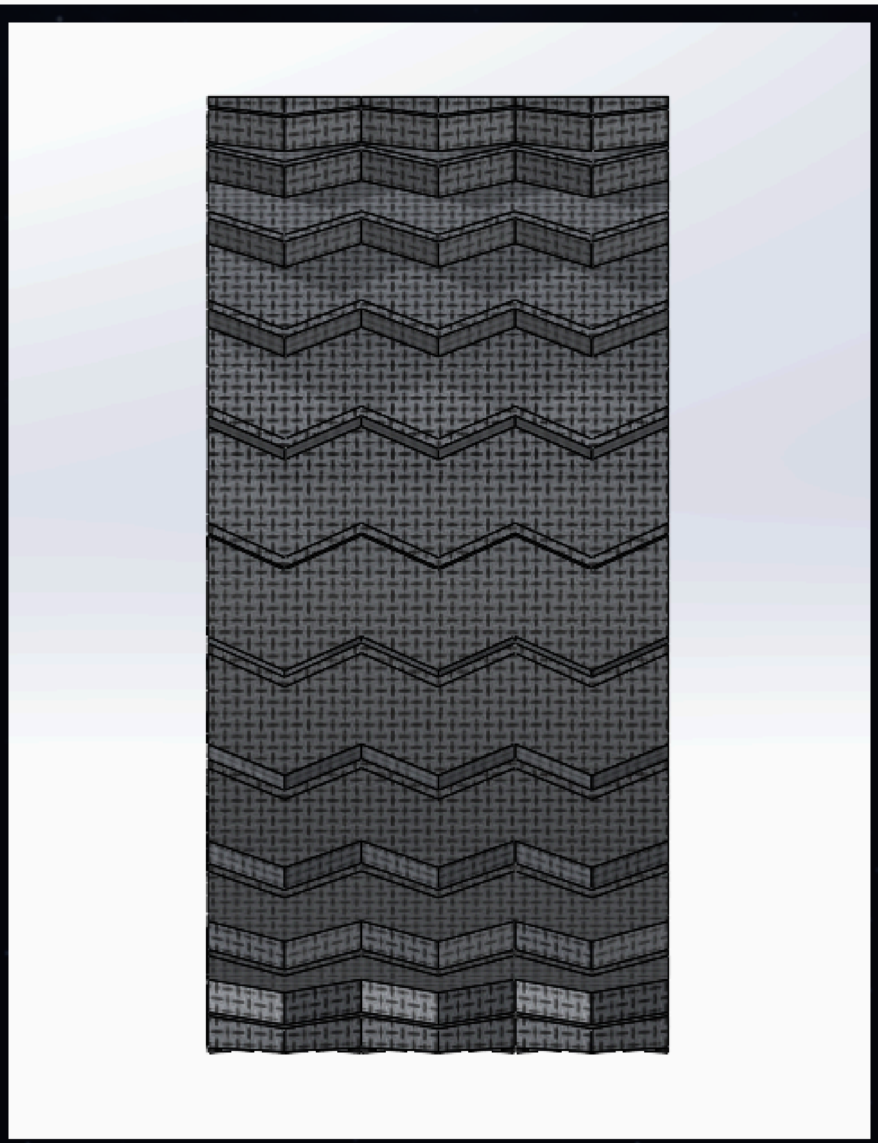
WHEEL DESIGN

Purpose of Design:

The wheel is engineered to ensure adaptability on Martian terrain, which includes rocky surfaces, loose soil, and potential obstacles. Emphasis is placed on traction, durability, and weight optimization for efficient navigation.

Key Design Features:

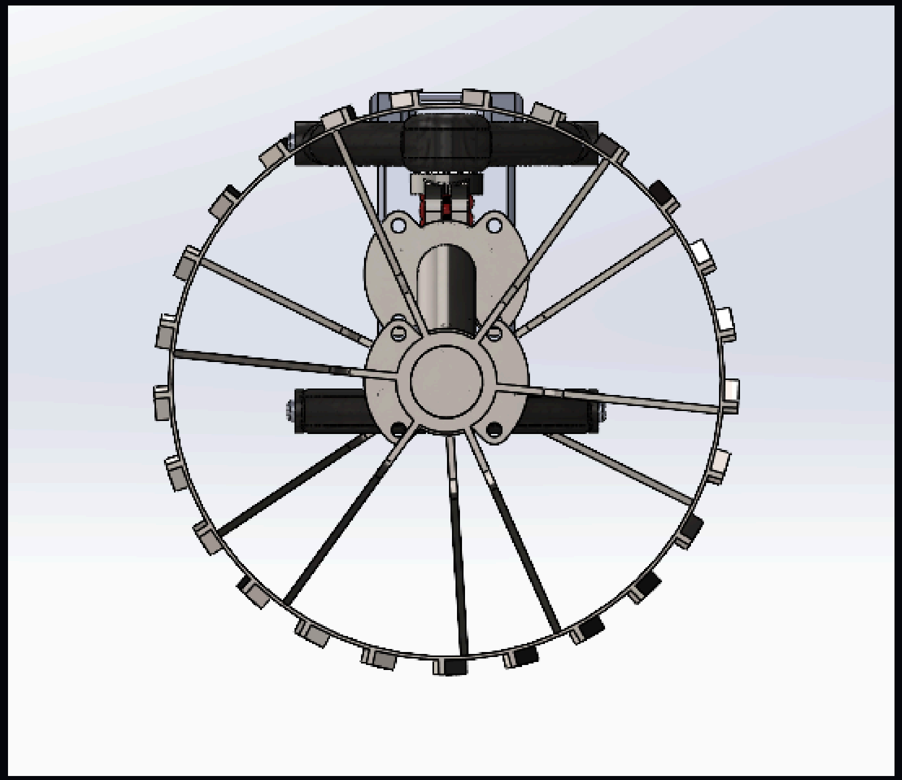
- Tread Pattern:
  - Chevron-style tread for maximum traction on loose and uneven Martian soil.
  - Prevents slippage and improves stability during climbs and turns.
- Rim Structure:
  - Open-lattice design ensures a lightweight yet strong frame, reducing material usage without compromising integrity.
  - Provides adequate space for dust clearance, reducing buildup and abrasion.

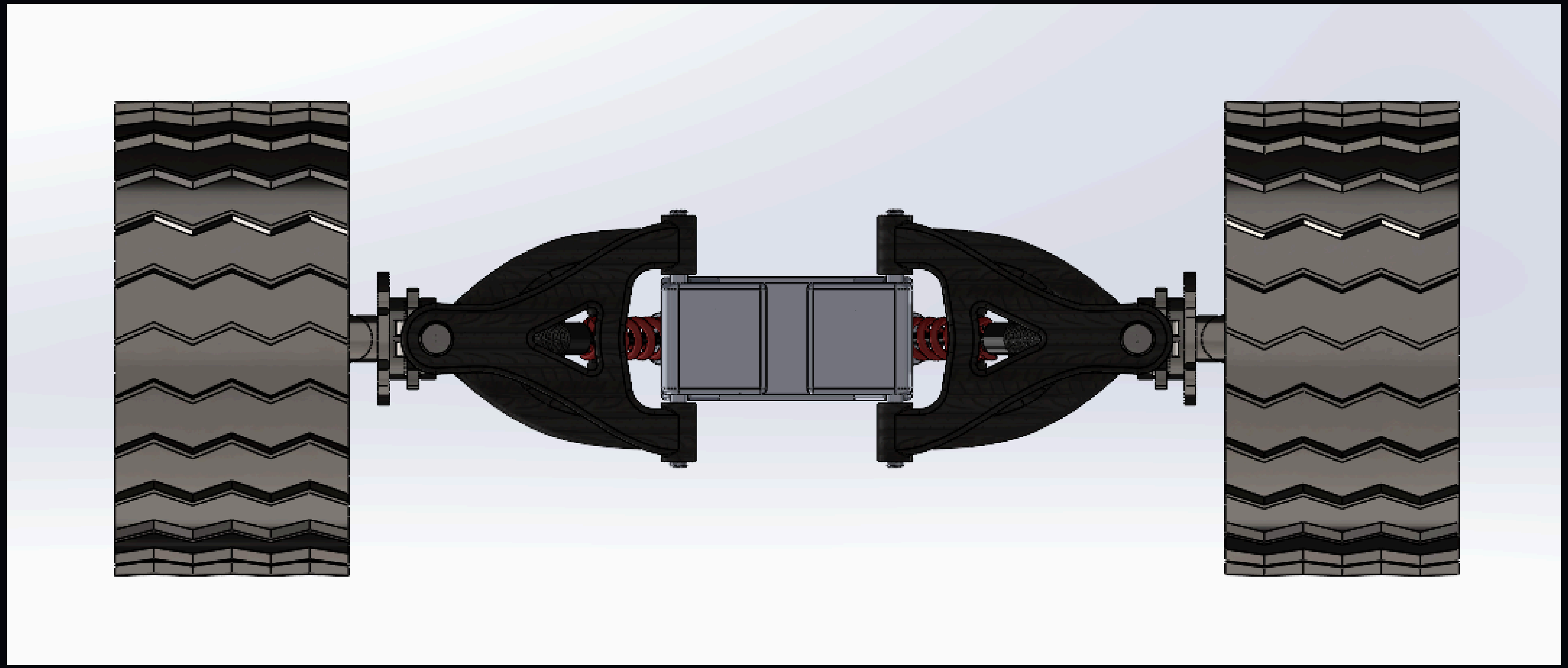


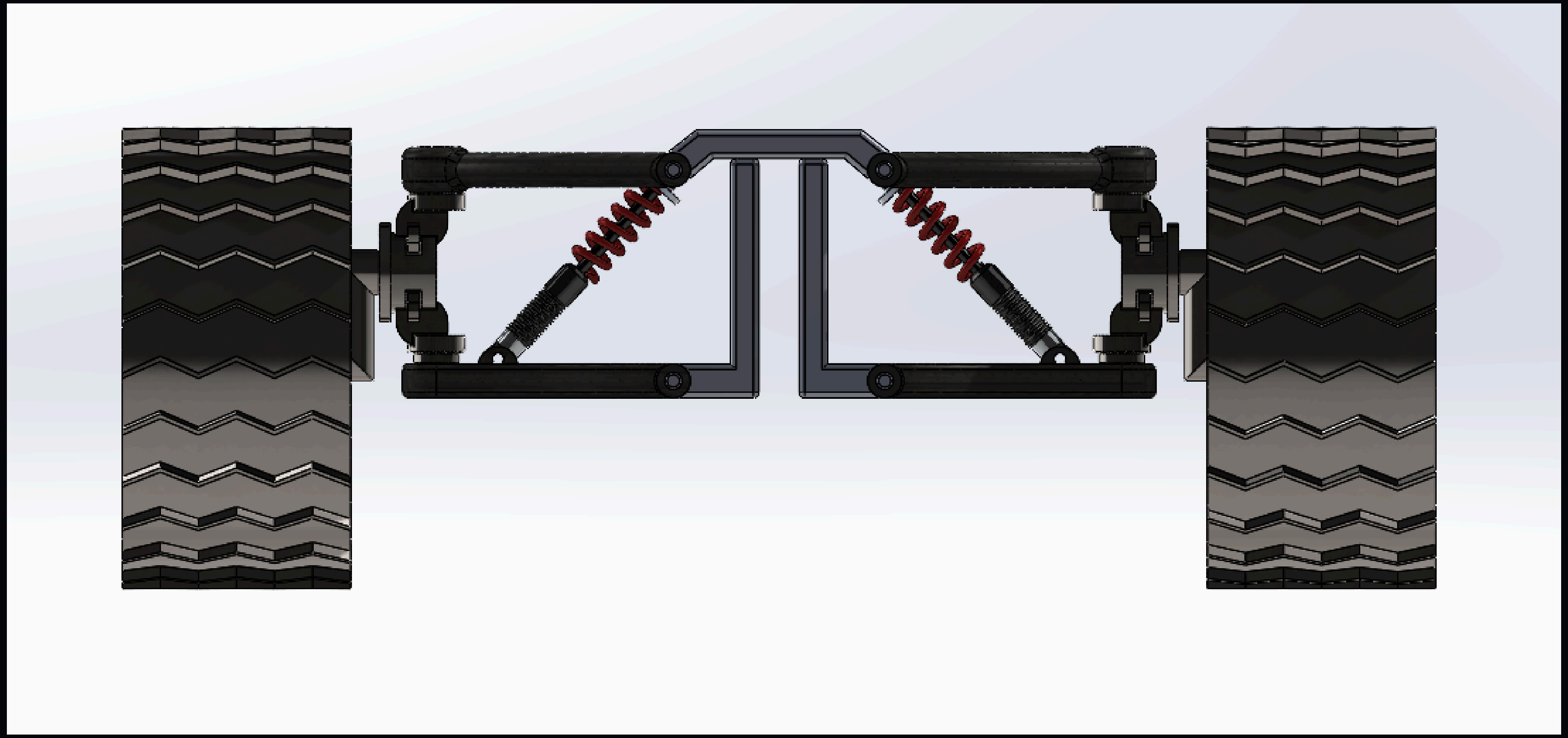
Design specifications:

Diameter: 0.77m
Width: 0.4m
No.of grouser: 25 nos
Grouser depth: 0.02m
Mass: 41.7 kg
Inner hub dia: 0.1m

WHEEL ASSEMBLY





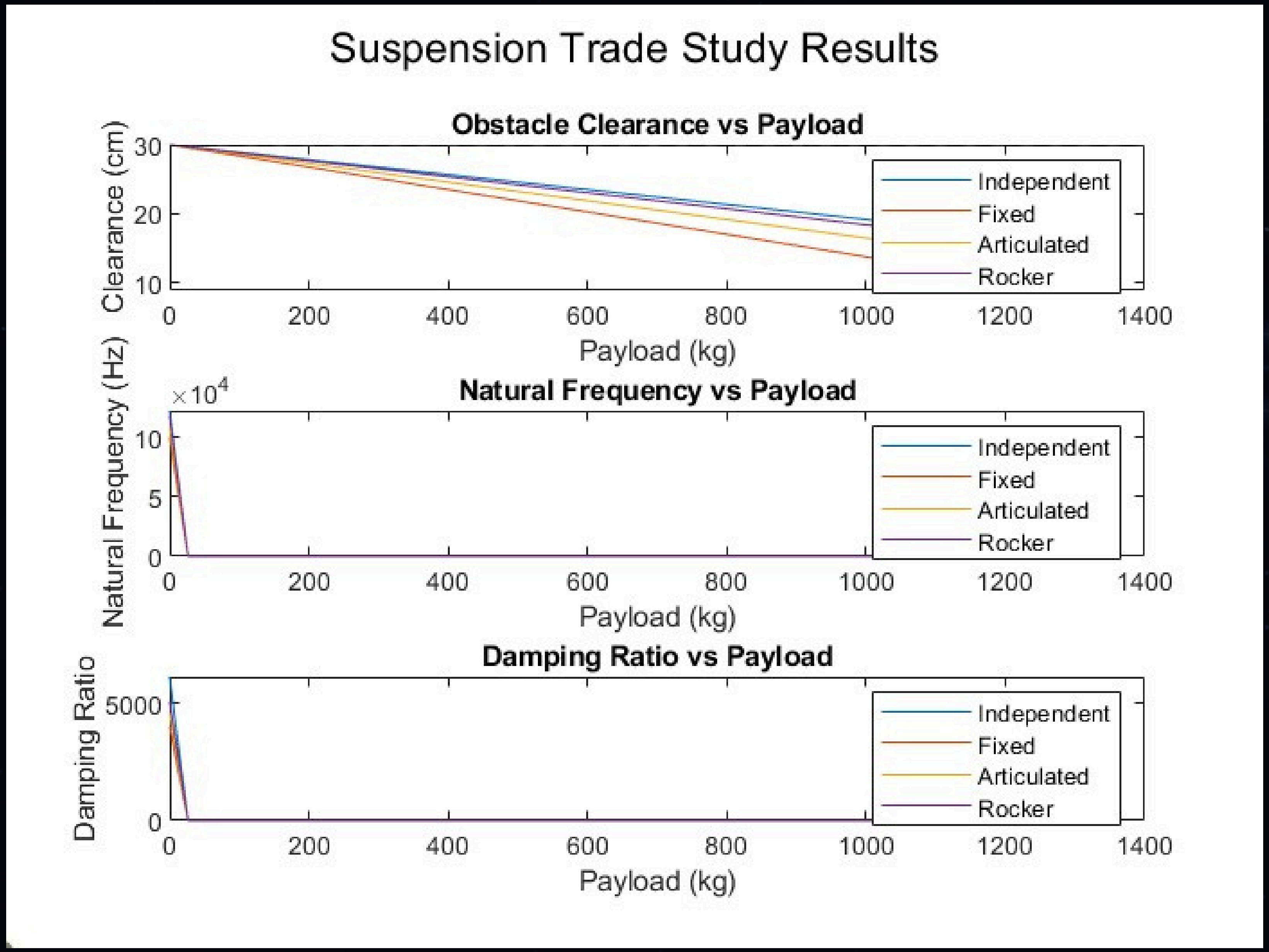


MATERIAL SELECTION

Key Material Selection:

1. Rim/Frame Material: Titanium Alloy (Ti-6Al-4V)
   - Properties:
     - High strength-to-weight ratio for durability under Martian terrain.
     - Excellent corrosion resistance for oxidative Martian soil.
     - Superior fatigue resistance for repeated impacts.
     - Handles extreme temperature fluctuations (-125°C to 20°C).
   - Why Titanium?: More robust than aluminum alloys and tougher than carbon fiber, ensuring long-term operation without deformation.
2. Tread Material: Nitrile Butadiene Rubber (NBR) with Kevlar Reinforcement
   - Base Layer (NBR):
     - High abrasion resistance for gritty Martian soil.
     - Flexible in low temperatures for superior grip.
   - Reinforcement (Kevlar):
     - Enhanced strength and puncture resistance.
   - Why NBR-Kevlar?: More adaptable than silicone rubber and more flexible than polyurethane, balancing durability and traction.
3. Dust Mitigation Coating: Polytetrafluoroethylene (PTFE)
   - Non-stick properties to prevent dust accumulation.
   - UV and oxidation-resistant for long-term efficiency.

SUSPENSION



- Key performance metrics such as obstacle clearance, natural frequency, and damping ratio are calculated for different suspension types under varying payload conditions.

- The payload is varied from 0 to the maximum allowable payload (1000 kg, including margins).

Which is Better:

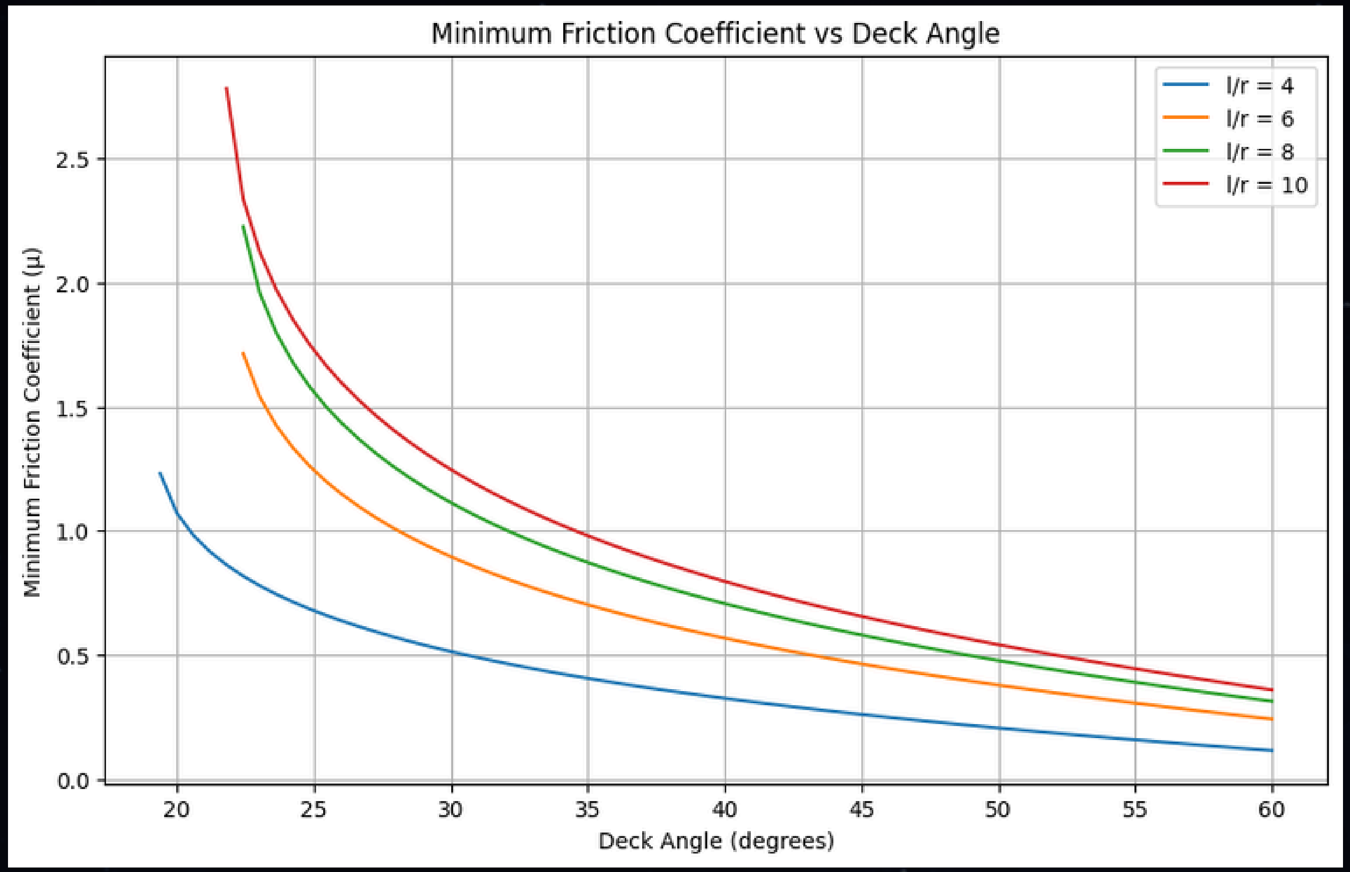
Independent Suspension:

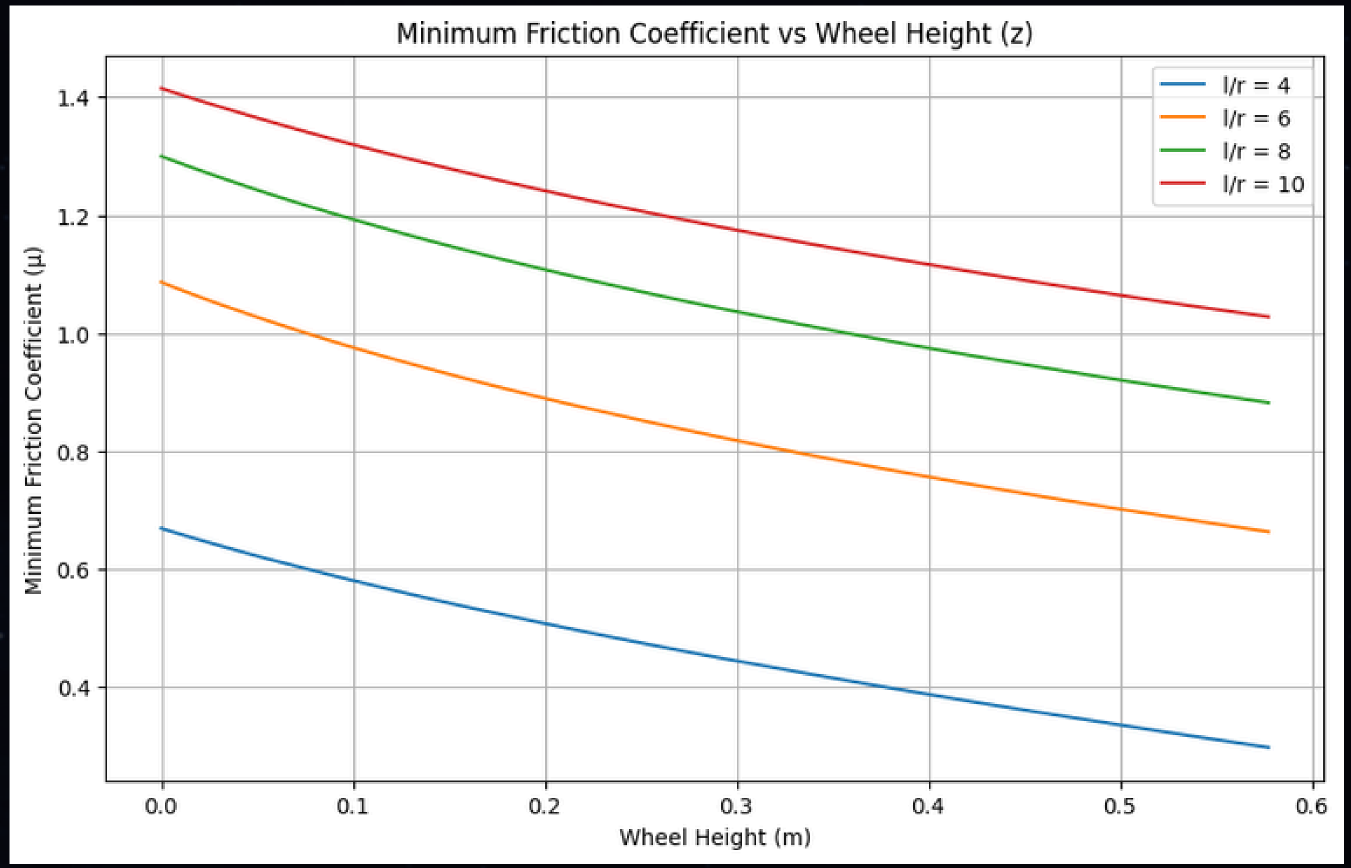
- Offers superior adaptability to varying payloads while maintaining a smooth ride and consistent obstacle clearance.
- Ideal for meeting the top speed and terrain-handling requirements outlined in the project.

Articulated and Rocker Suspension:

- Better suited for extremely rugged terrains but may compromise ride smoothness or payload adaptability compared to independent suspension.

TRACTION ANALYSIS



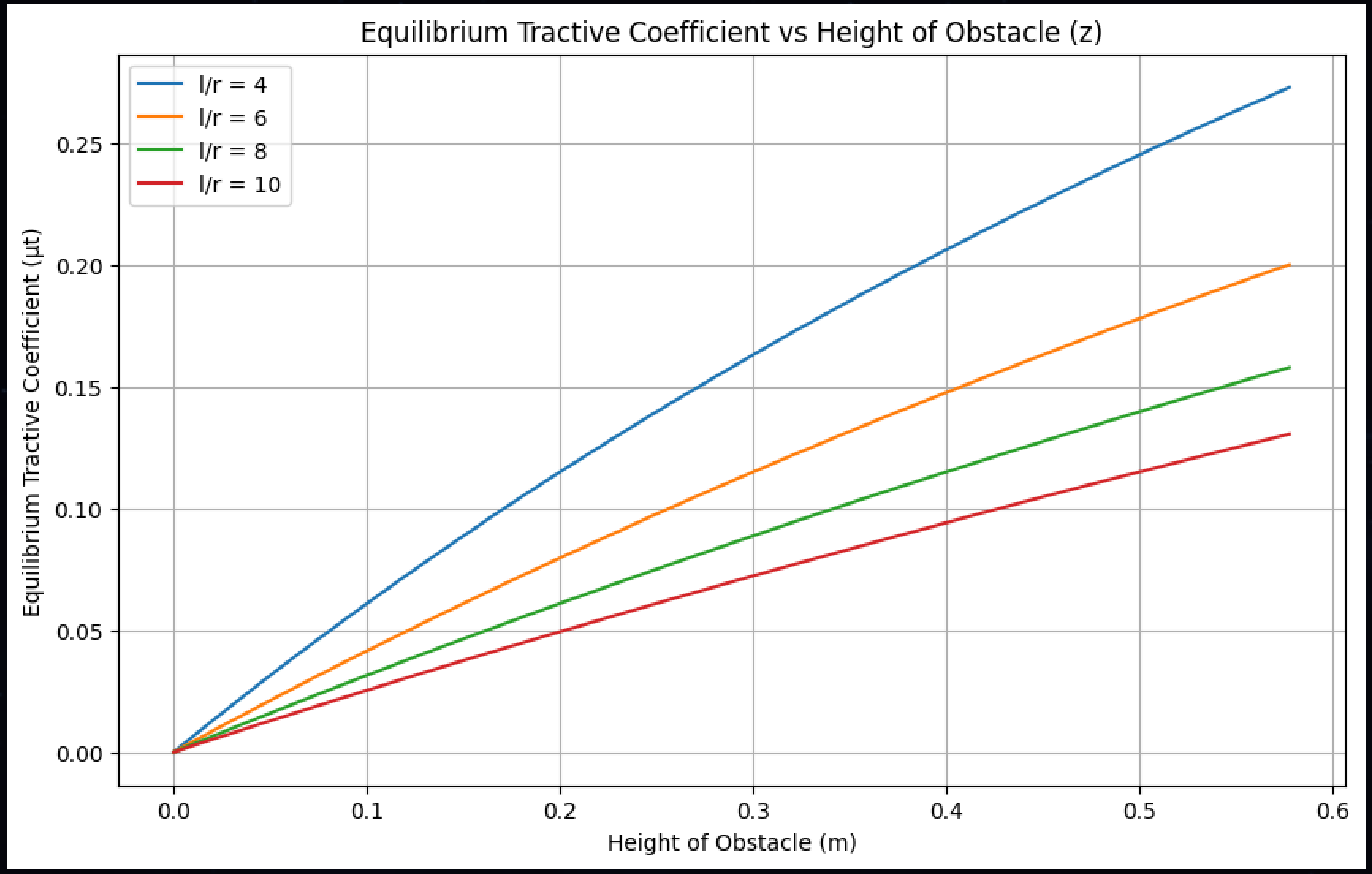


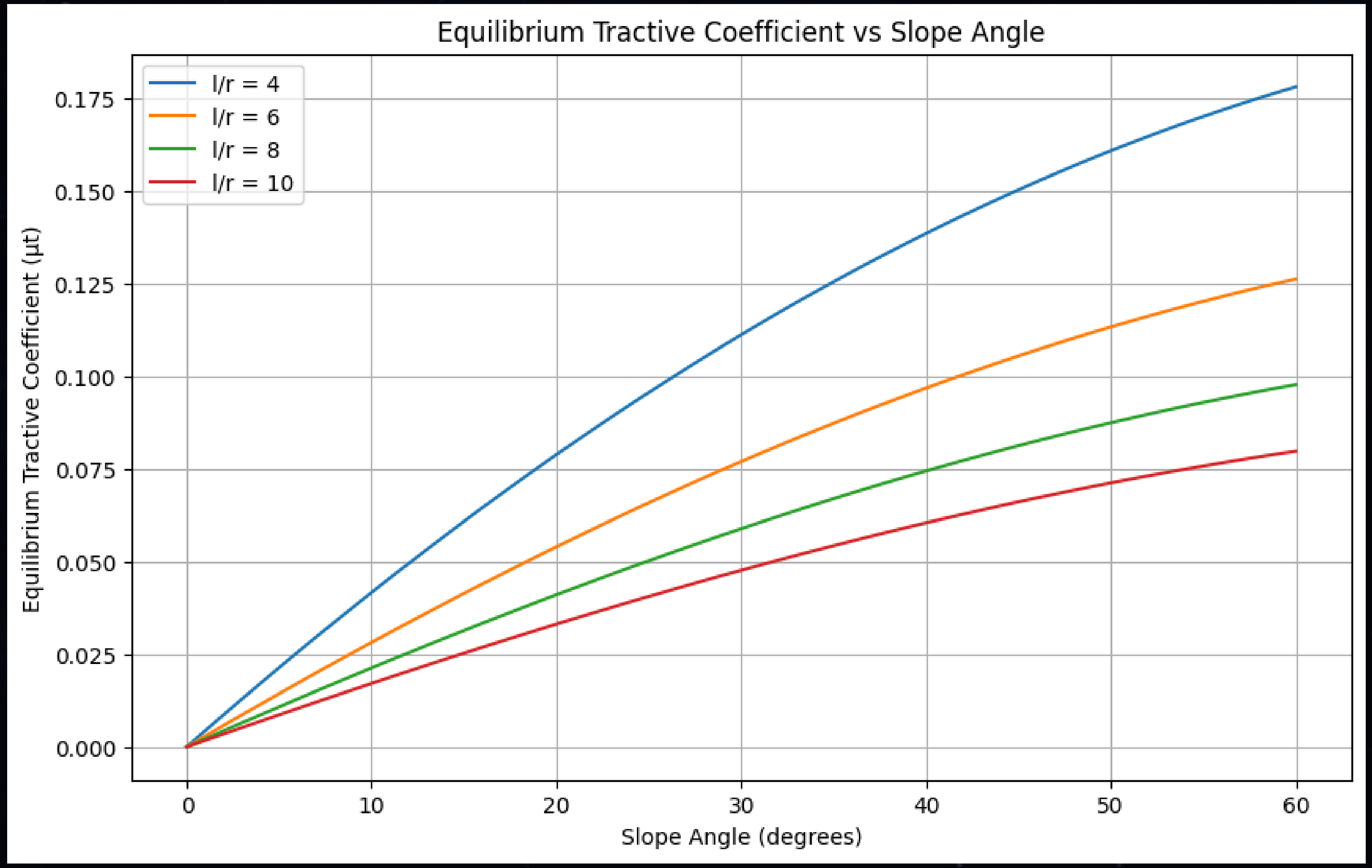
Evaluate traction and friction requirements for rover wheels under varying slope angles and slope heights.

Insights:

- Deck Angle Impact: Higher deck angles require increased friction to prevent slipping.
- Obstacle Height Influence: As obstacle height increases, tractive coefficient requirements rise.
- Slope Stability: The tractive coefficient needed grows with steeper slopes, emphasizing design trade-offs.

TRACTION ANALYSIS





SUSPENSION TRADE STUDY

Suspension Type	Description	Advantages	Disadvantages
Torsion Bar Suspension	Uses torsion bars that twist to absorb shocks and provide a spring effect	- Compact and relatively lightweight - No external coils or leaf springs	Inefficient on rough terrain
Leaf Spring Suspension	Utilizes layered metal springs that flex to absorb impacts	- Simple and robust - Proven technology	Struggles on rugged surfaces
Coil Spring & Damper	Springs compress to absorb shocks while dampers control rebound	- Good energy absorption and ride quality - Easier to tune for different terrain conditions	Poor on rough terrain
Trailing Arm Suspension	Wheels mounted on pivoting arms that trail from the chassis	- Good ground contact and stability - Better shock absorption than rigid setupsge turn radius	Slightly better on rough terrain
Double Wishbone Suspension	Uses upper and lower “A”-shaped arms to hold each wheel, allowing controlled wheel travel	- Excellent wheel control and stability - Adaptable to uneven terrain	Excellent on rough, uneven terrain

SUSPENSION - DOUBLE WISHBONE

Design Specifications:

Dimensions:

1. Wishbone Length: 400 mm
    - Optimized for the wheel radius and ground clearance.
2. Spring Travel: 50-200 mm
    - Sufficient movement for absorbing shocks from rocks and terrain changes.
3. Damper Rod Diameter: 160 mm
    - Ensures durability under repeated stresses.

Mass:

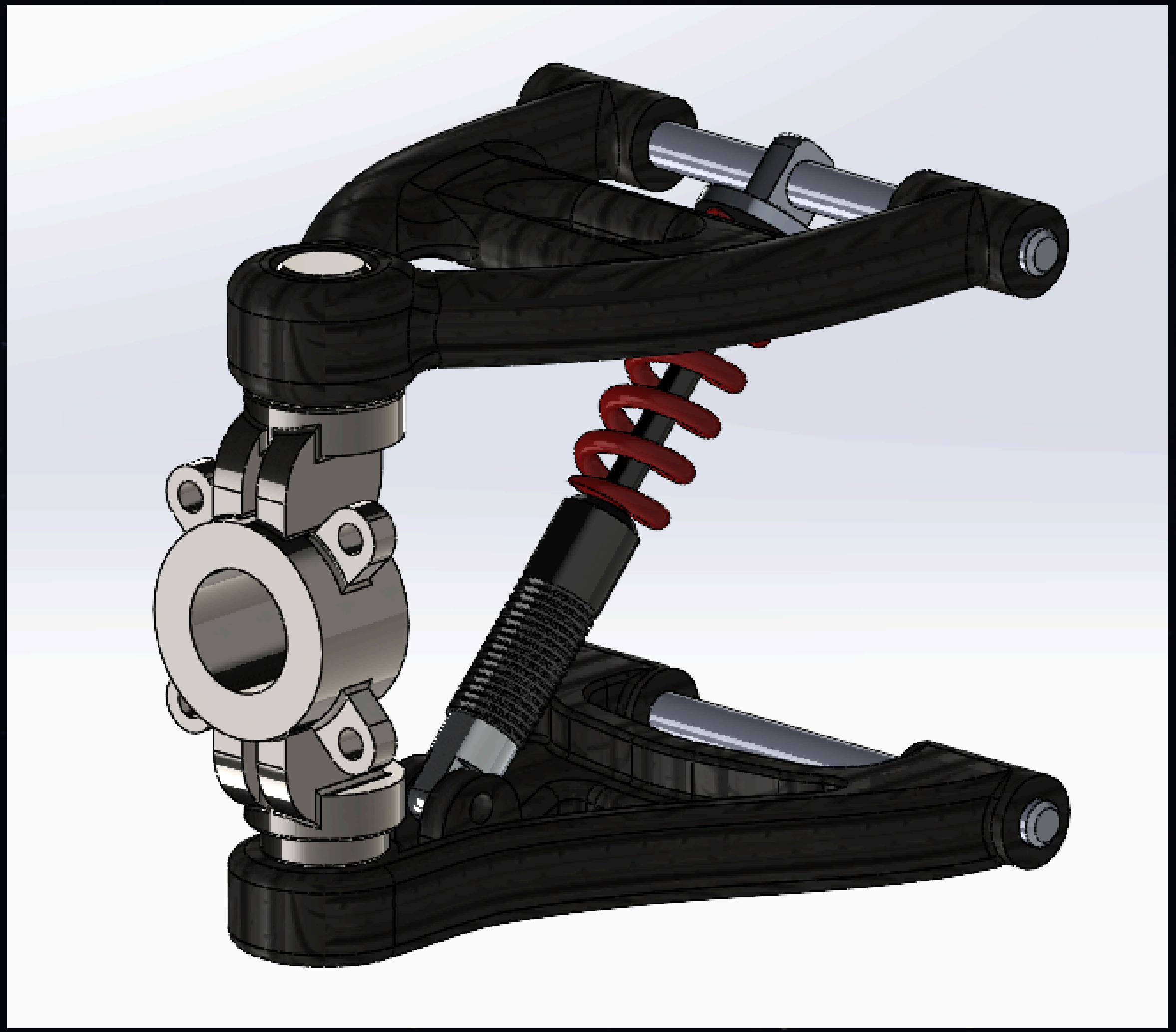
- Each Suspension Assembly: ~10 kg
    - Lightweight materials keep the total rover weight within mission constraints.

Thermal Considerations:

- Operational in -125°C to 20°C, with material properties optimized for extreme Martian temperatures.

Dust Protection:

- PTFE-coated joints ensure longevity by reducing friction and mitigating the abrasive effects of Martian soil.



MATERIAL SELECTION

1. Suspension Arms Material: Carbon Fiber Reinforced Polymer (CFRP)
- Lightweight: Reduces overall system weight for efficient mobility.
- High Strength: Handles dynamic stresses from terrain impacts.
- Fatigue Resistance: Ensures long-term durability on uneven Martian terrain.

Comparison:
- Aluminum: Heavier and less resistant to fatigue.
- Steel: Strong but significantly heavier.
- Titanium: High strength but costlier and less lightweight than CFRP.

2. Spring Material: Titanium Alloy (Ti-6Al-4V)
- High Strength-to-Weight Ratio: Ideal for weight-sensitive components.
- Corrosion Resistance: Essential for Martian conditions.
- Fatigue Resistance: Handles repeated compression and tension cycles.

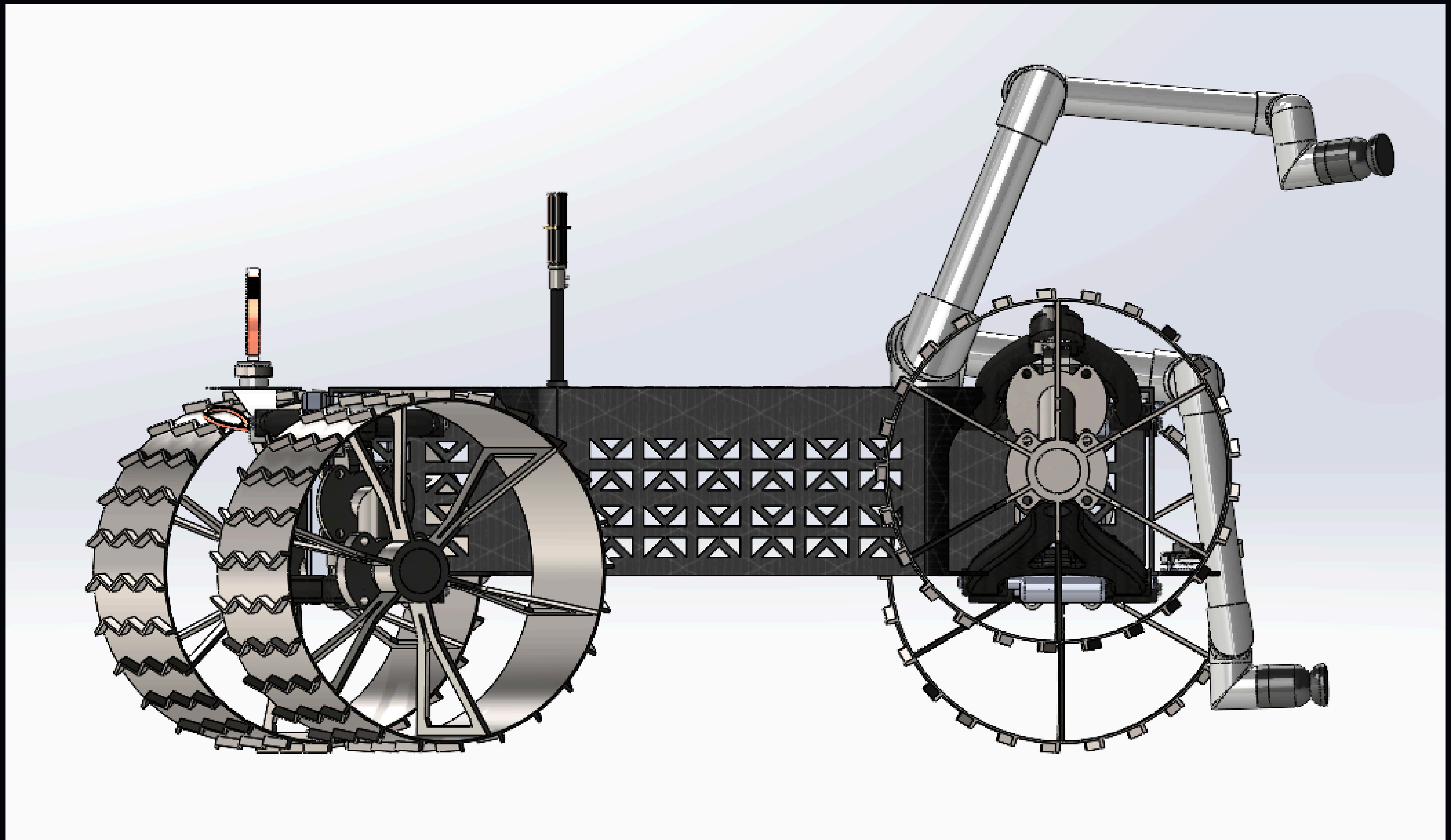
Comparison:
- Steel: Fatigue-resistant but much heavier.
- Aluminum: Lacks the necessary strength for springs.

3. Damper Rod Material: Hardened Stainless Steel (Grade 440C)
- Wear Resistance: Handles repeated sliding and damping motion without degradation.
- Corrosion Resistance: Protects against oxidation in Martian soil.

Comparison:
- Plain Steel: Prone to wear and corrosion.
- Titanium: Durable but costlier for non-critical components.

4. Coating for Joints and Moving Parts - Material: Polytetrafluoroethylene (PTFE)
- Dust Mitigation: Prevents Martian dust from accumulating and interfering with movement.
- Friction Reduction: Ensures smooth operation and reduces wear.

SUSPENSION



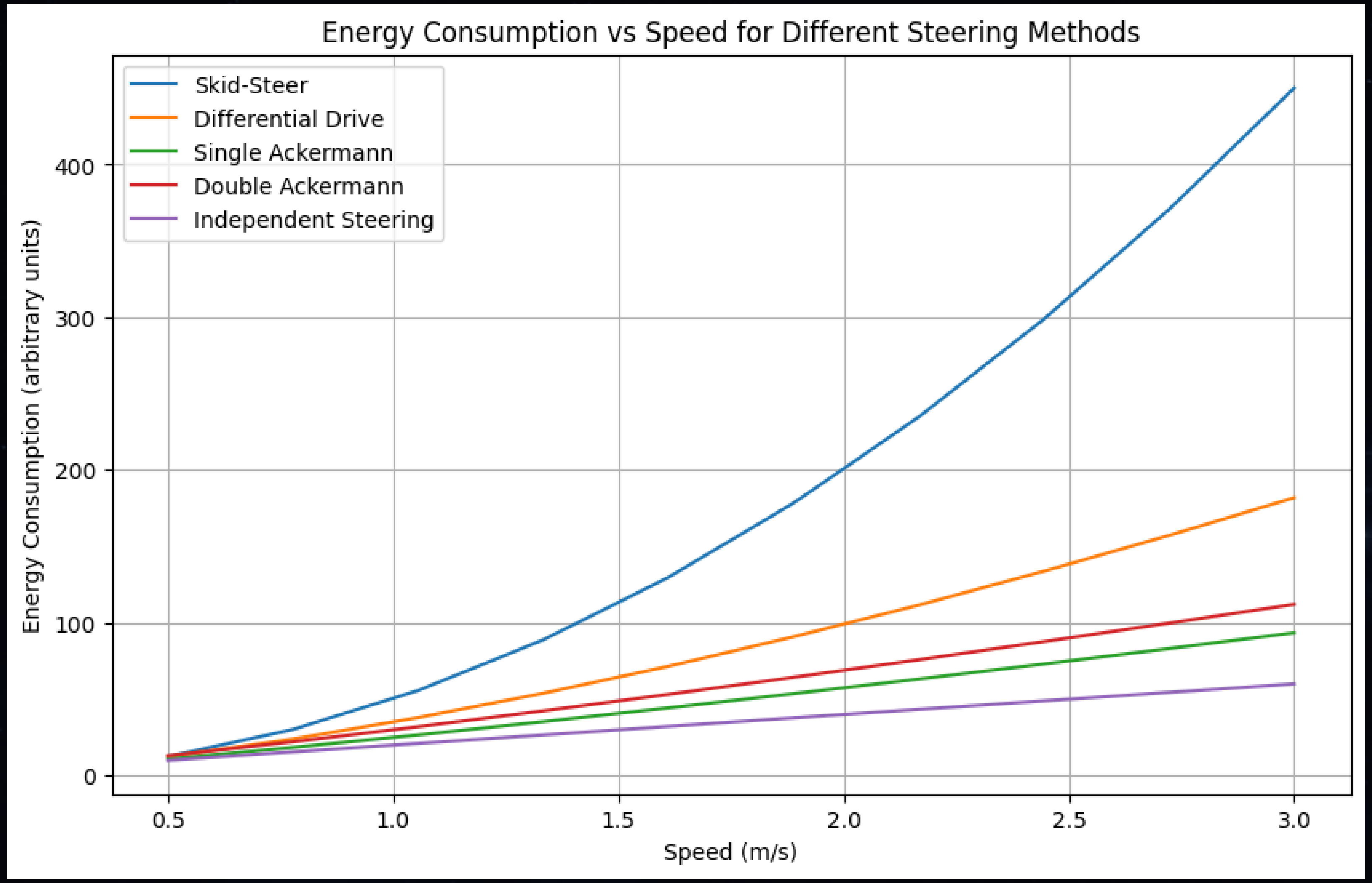
Suspension climbing a height of 30 cm which is the max obstacle height.

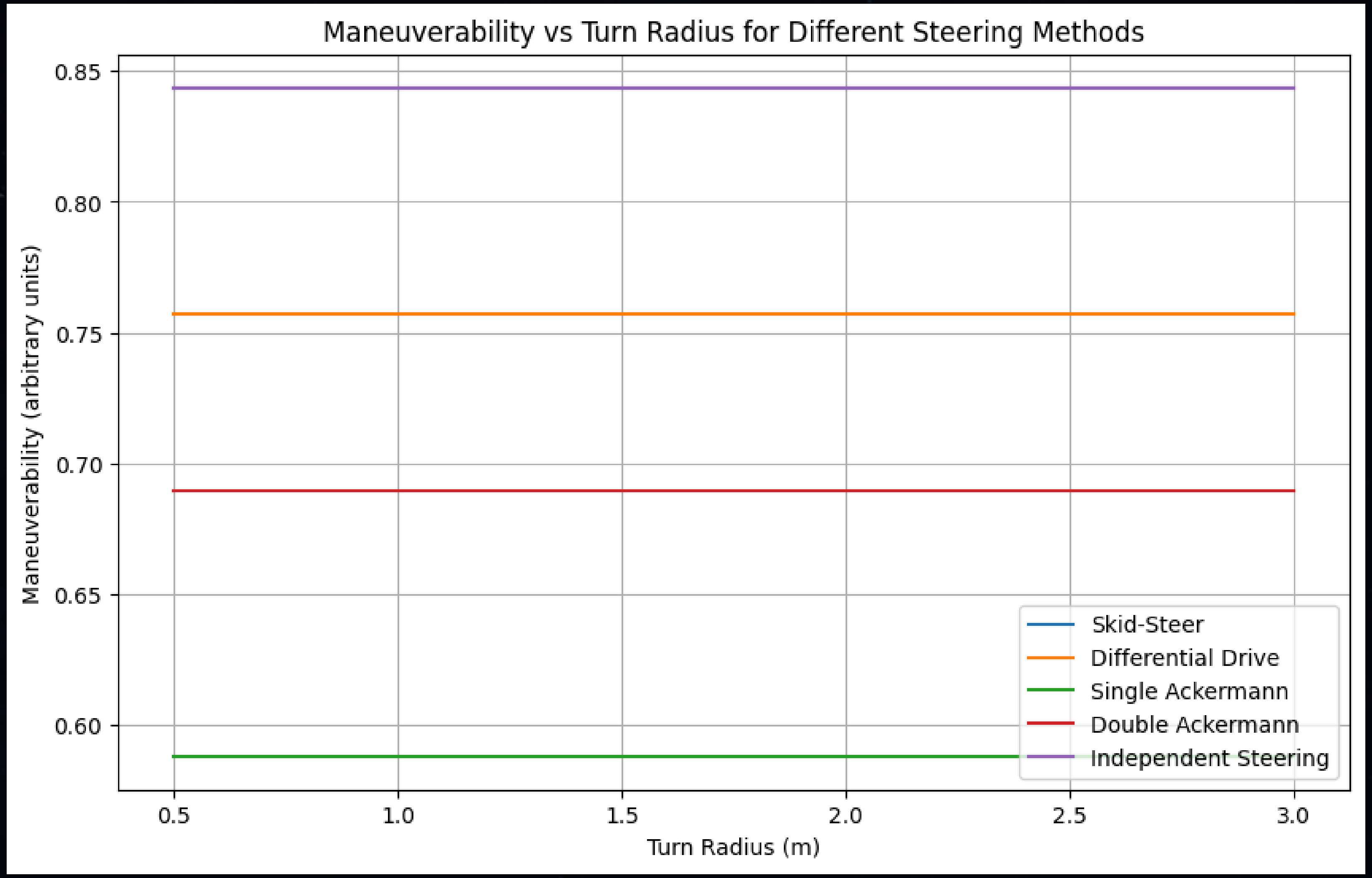
STEERING

Key Considerations for Trade Study:

Steering System	Energy Consumption	Maneuverability	Terrain Adaptability	Complexity
Skid-Steer	High, especially on rough terrain	High, effective in tight spaces	Inefficient on rough terrain	High mechanical complexity
Differential	Moderate, efficient on flat terrain	Moderate, limited to larger turns	Struggles on rugged surfaces	Simple, low maintenance
Single Ackermann	Moderate, better than skid-steer	Low, large turn radius	Poor on rough terrain	Low complexity, relatively simple design
Double Ackermann	Moderate, better than skid-steer	Low, large turn radius	Slightly better on rough terrain	Low complexity
Independent	Low, efficient across varied terrains	Very high, tight turn radius	Excellent on rough, uneven terrain	Higher mechanical complexity

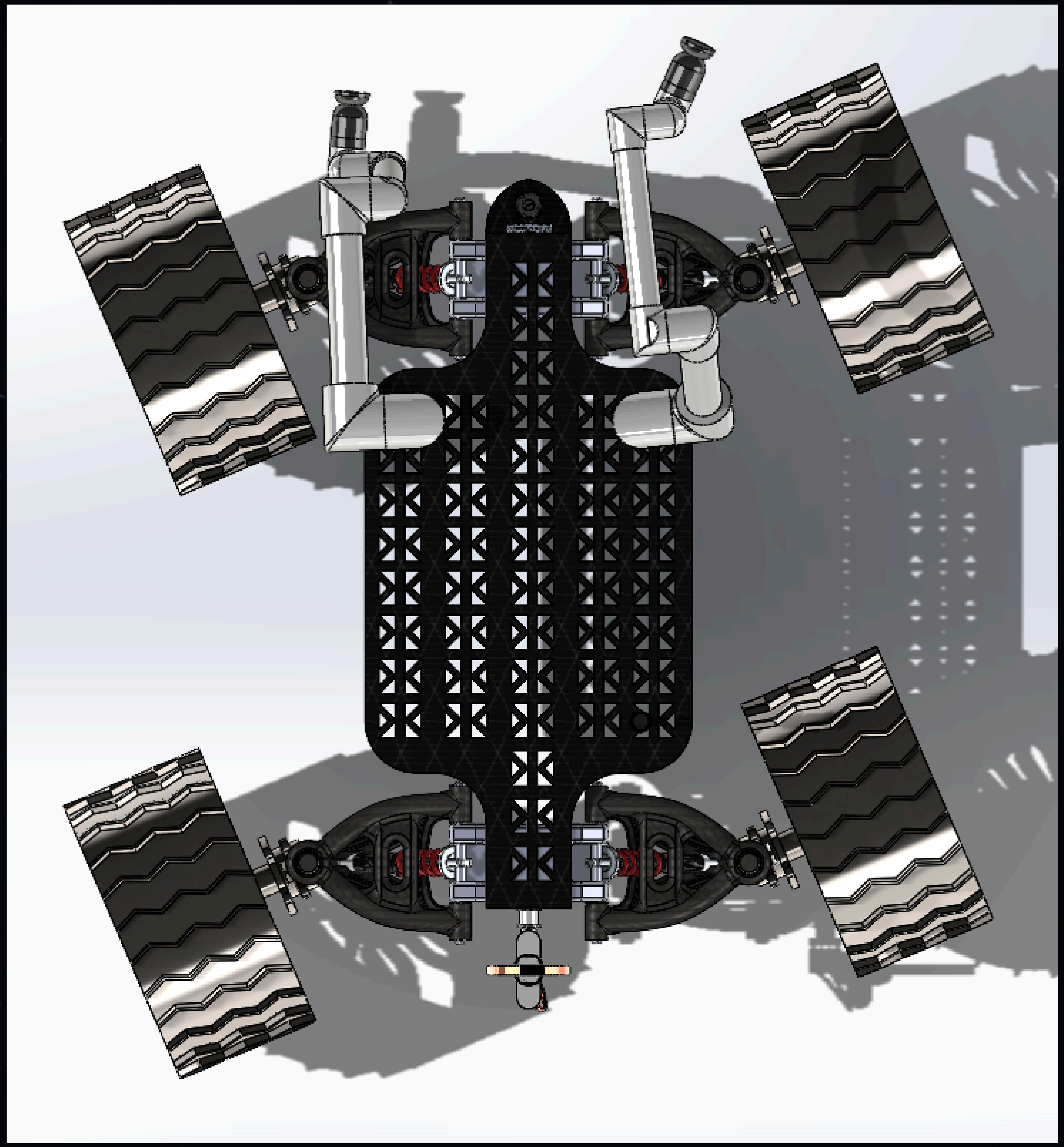
STEERING





Independent Steering provides the best balance for energy efficiency, maneuverability, and adaptability to rough terrain, making it the most suitable for the lunar mission.

STEERING



CHASIS

Dimensions:

1. Outer Frame Dimensions: Customizable based on payload and system requirements (e.g., 600 mm x 400 mm x 200 mm for a mid-sized rover).
2. Wall Thickness: 10 mm for CFRP panels to balance lightweight design and structural rigidity.
3. Integrated Lattice:
   - Reduces weight without compromising structural strength.
   - Triangular cutouts optimize load distribution and improve thermal dissipation.

Weight:

- Entire chassis structure: 77.46 kg depending on dimensions and integration points.

Load-Bearing Capacity:

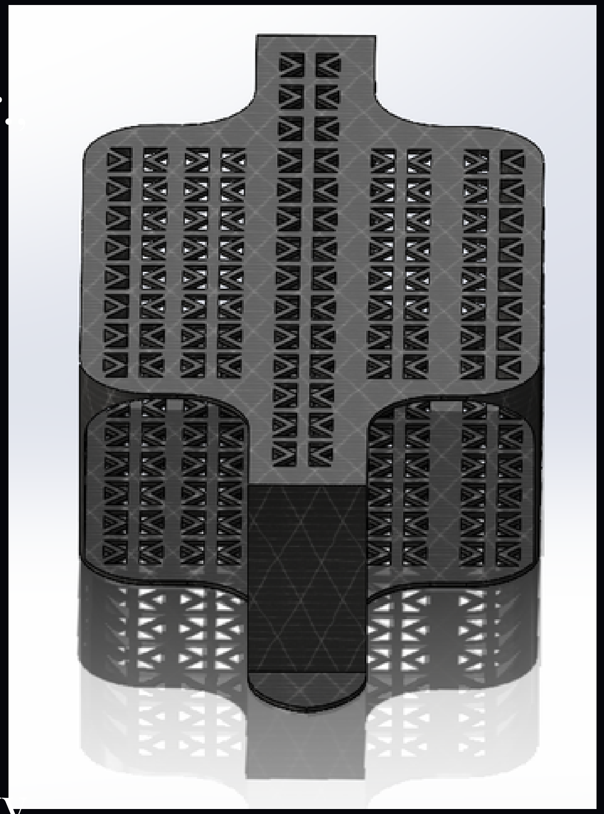
- Designed to handle payloads of 1000 kg, ensuring stability under equipment and mobility systems.

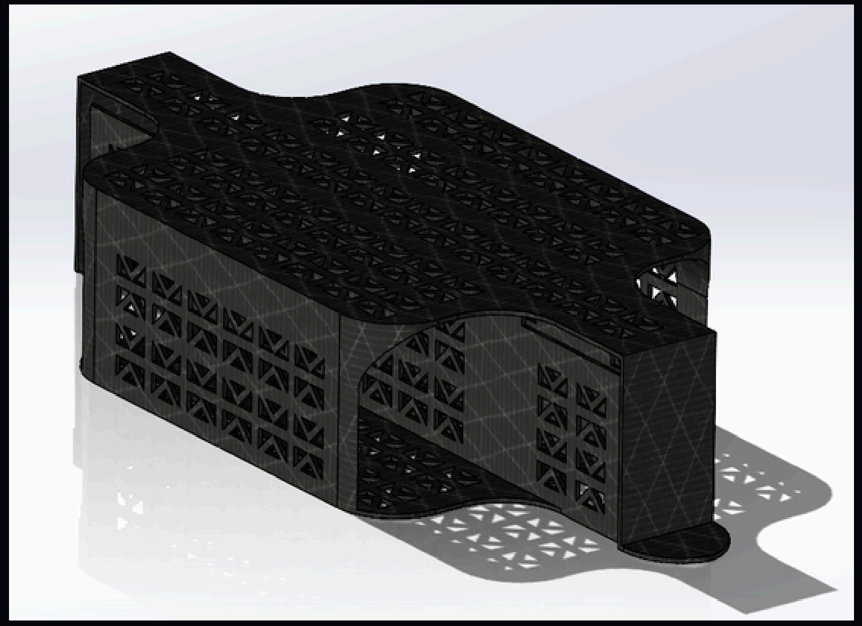
Thermal and Dust Considerations:

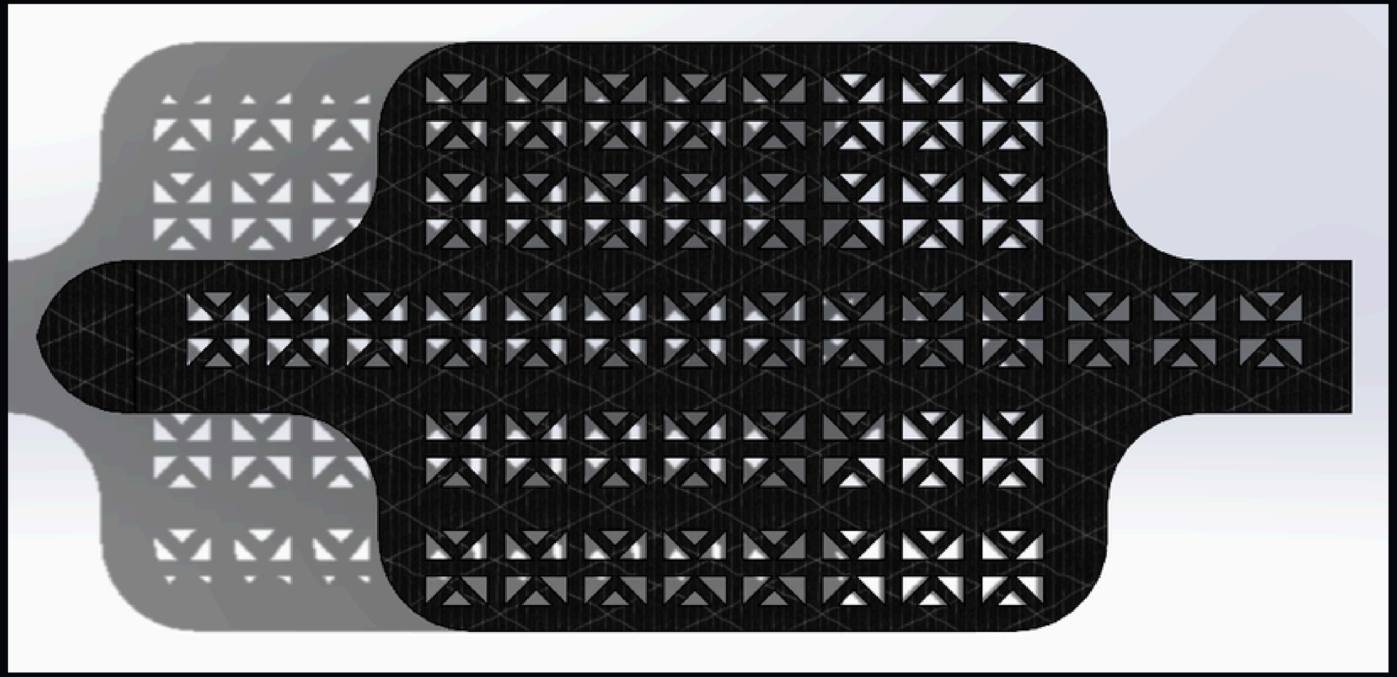
- Operational in -125°C to 20°C, with thermal insulation protecting electronics and internal components.
- Dust-resistance features include sealed compartments and smooth coated surfaces to minimize abrasive effects.

Integration Points:

- Mounting points for:
  - Suspension System: Reinforced with embedded CFRP ribs.
  - Electronics Bay: Protected and insulated compartment for critical systems.
  - Payload Systems: Adjustable mounting brackets to accommodate mission-specific equipment.







MATERIAL SELECTION

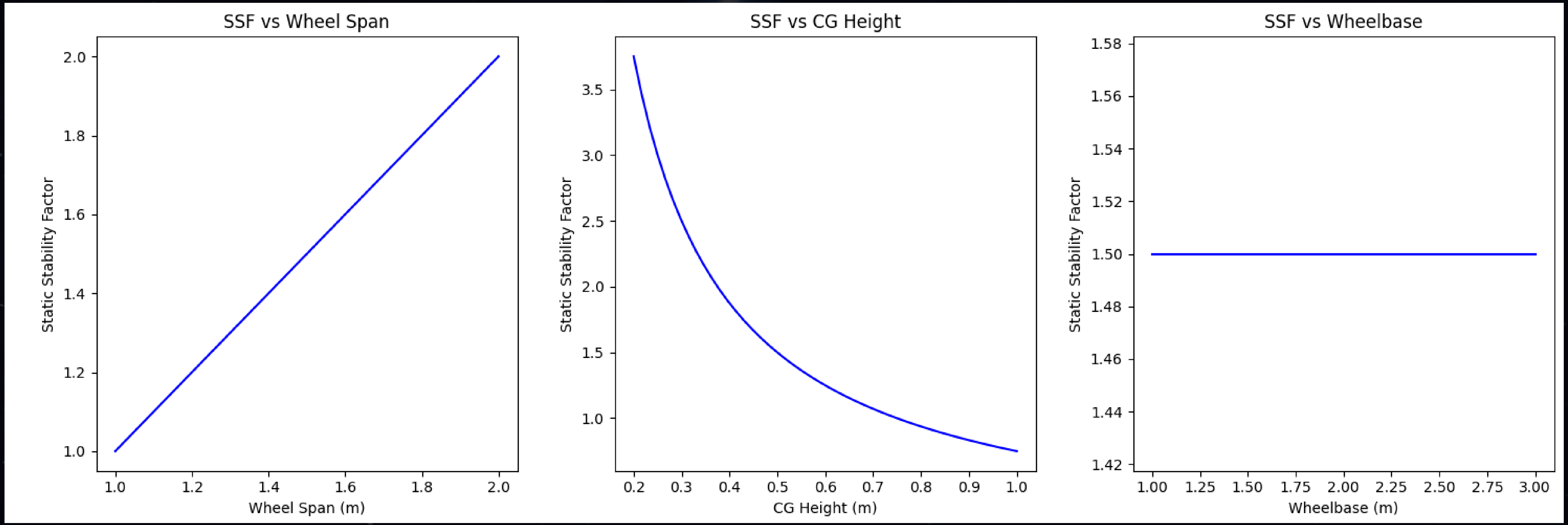
1. Base Material: Carbon Fiber Reinforced Polymer (CFRP)
   - Properties:
     - Lightweight: Extremely high strength-to-weight ratio, reducing overall rover mass for efficient operation and lower launch costs.
     - Durability: Resists cracking, deformation, and fatigue under dynamic loads.
     - Thermal Stability: Maintains structural integrity in extreme Martian temperature conditions (-125°C to 20°C).
     - Corrosion Resistance: Inert to the oxidative Martian environment, ensuring long-term operation.
   - Comparison:
     - Aluminum Alloy 6061-T6: Heavier and less resistant to fatigue under repeated loading.
     - Titanium Alloy: Strong and corrosion-resistant but significantly more expensive and heavier than CFRP.
     - Steel: Incredibly strong but impractically heavy for space missions.
   - Reason for Selection: CFRP ensures an ideal balance of lightweight design and mechanical durability, critical for the chassis' performance on Mars.
2. Coating: Thermal Barrier Coating (TBC)
   - Base Coating: Ceramic-based thermal protective layer.
   - Properties:
     - Reflects solar radiation to minimize heat absorption and protect internal components.
     - Acts as an insulator to withstand and regulate extreme Martian thermal fluctuations.
     - Provides additional abrasion resistance against Martian dust storms.
   - Comparison:
     - Uncoated CFRP: Susceptible to thermal cycling stress over extended durations.
     - Polymer Coating: Less durable under abrasive conditions and prone to wear.
   - Reason for Selection: TBC enhances the durability and thermal performance of CFRP, ensuring the chassis can withstand Mars' harsh environment.

BOE STABILITY

Analyzing static stability for a rover using the Back of Envelope (BOE) stability analysis involves evaluating the rover's center of gravity (CG), wheelbase (distance between front and rear wheel), and wheel span (distance between left and right wheel) to ensure it remains stable under static conditions.

$$SSF = \frac{\text{Wheel Span}/2}{\text{Height of CG}}$$

A higher SSF indicates greater stability. An SSF > 1 is generally considered stable.



STABILITY DURING CLIMBING

Obstacle Climbing Feasibility:

- The rover's maximum obstacle height (30 cm) is compared to its wheel radius (35 cm). The analysis confirms that the rover can climb the obstacle as the height is within the wheel's capability.

Approach Angle:

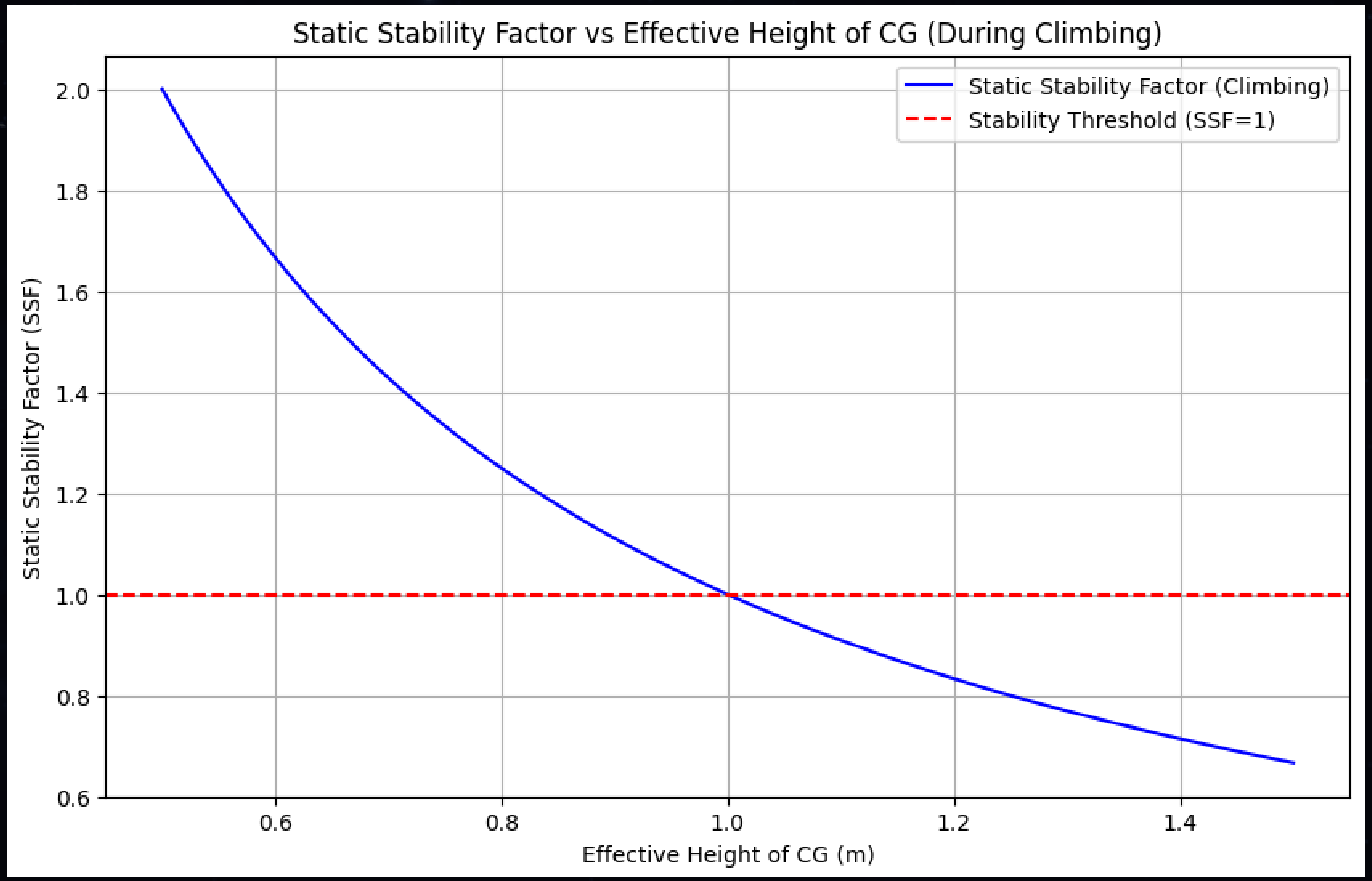
- The approach angle for the rover is calculated as 8.53°, ensuring that the chassis won't scrape during climbing.

Static Stability During Climbing:

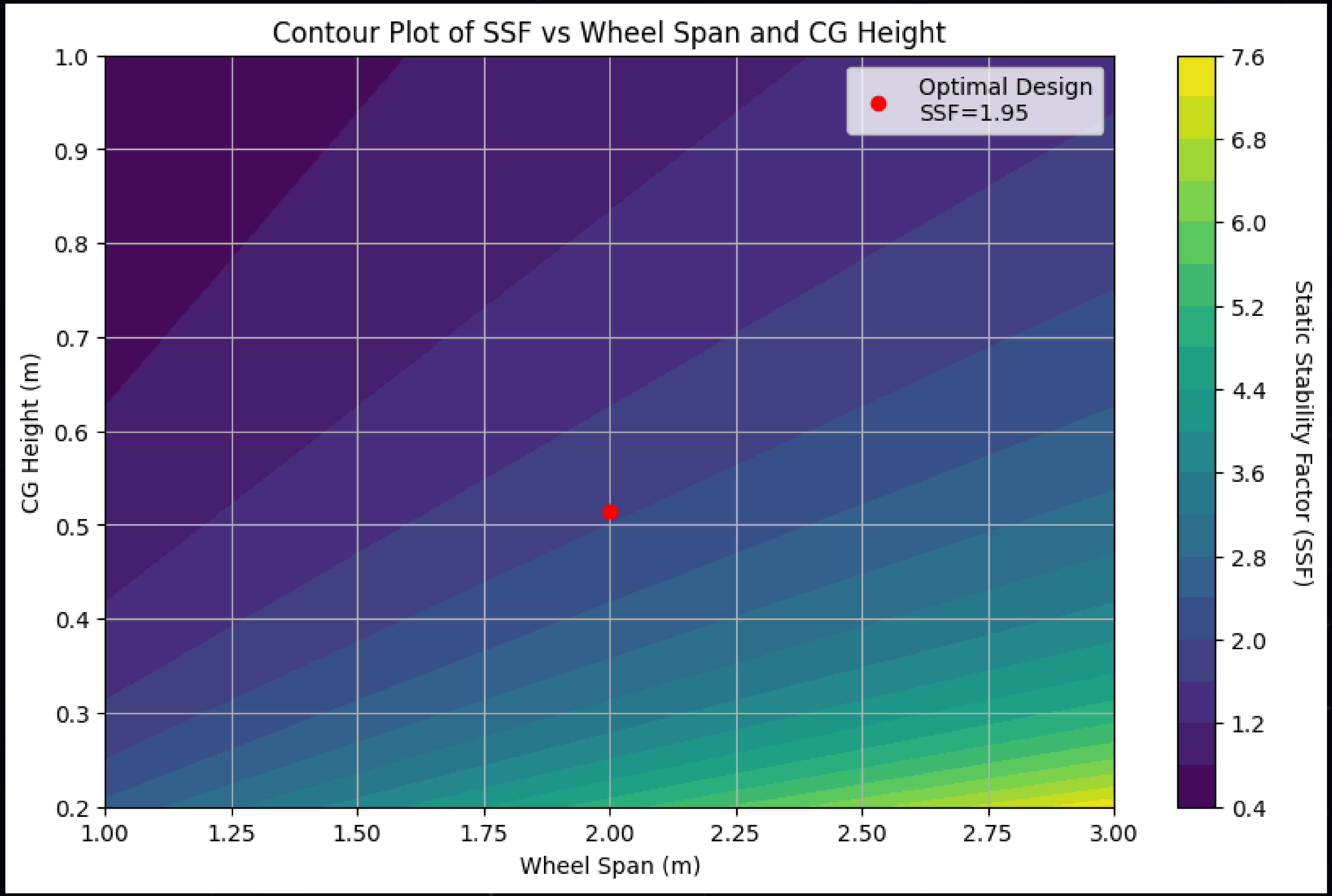
- The Static Stability Factor (SSF) is analyzed by considering the effective height of the CG (CG height + obstacle height = 0.558). The rover remains stable (SSF > 1) throughout the climb.

Conclusion:

- The rover design meets the stability and geometry requirements for climbing obstacles up to 30 cm while maintaining sufficient clearance and stability.



OPTIMAL VALUE OF CG & WHEEL SPAN



The optimal values for wheel span, wheelbase, and center of gravity (CG) height are calculated using constrained optimization.

Objective Function

The objective function combines three factors:

1. Static Stability Factor (SSF): A measure of the rover's resistance to tipping over.
2. Soil Sinkage: Lower sinkage is better; higher sinkage contributes negatively to performance.
3. Rolling Resistance: Represents the energy needed to move the rover over the terrain. Lower resistance is better

The combined objective function is:

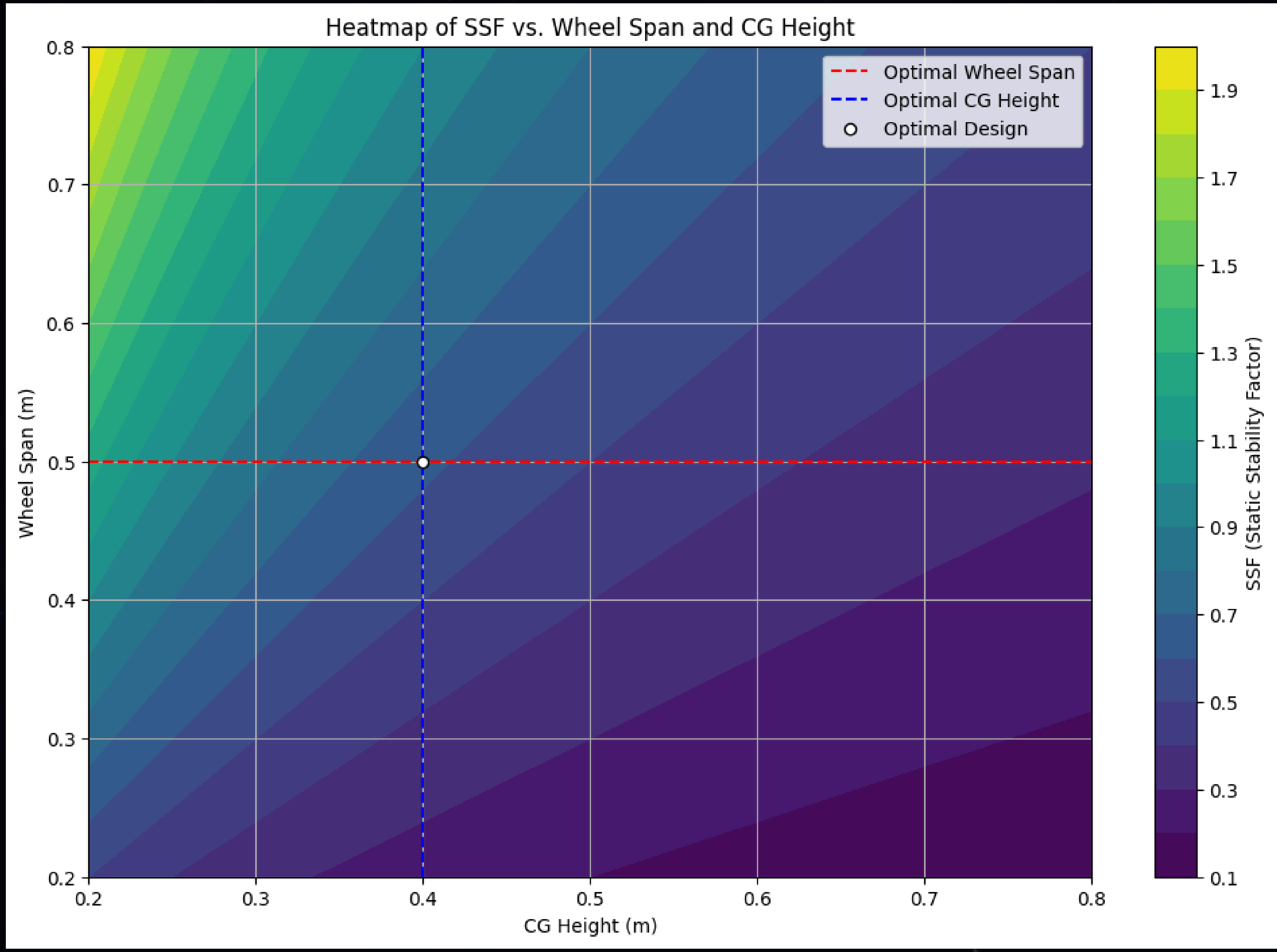
Objective=−SSF+Sinkage+Resistance

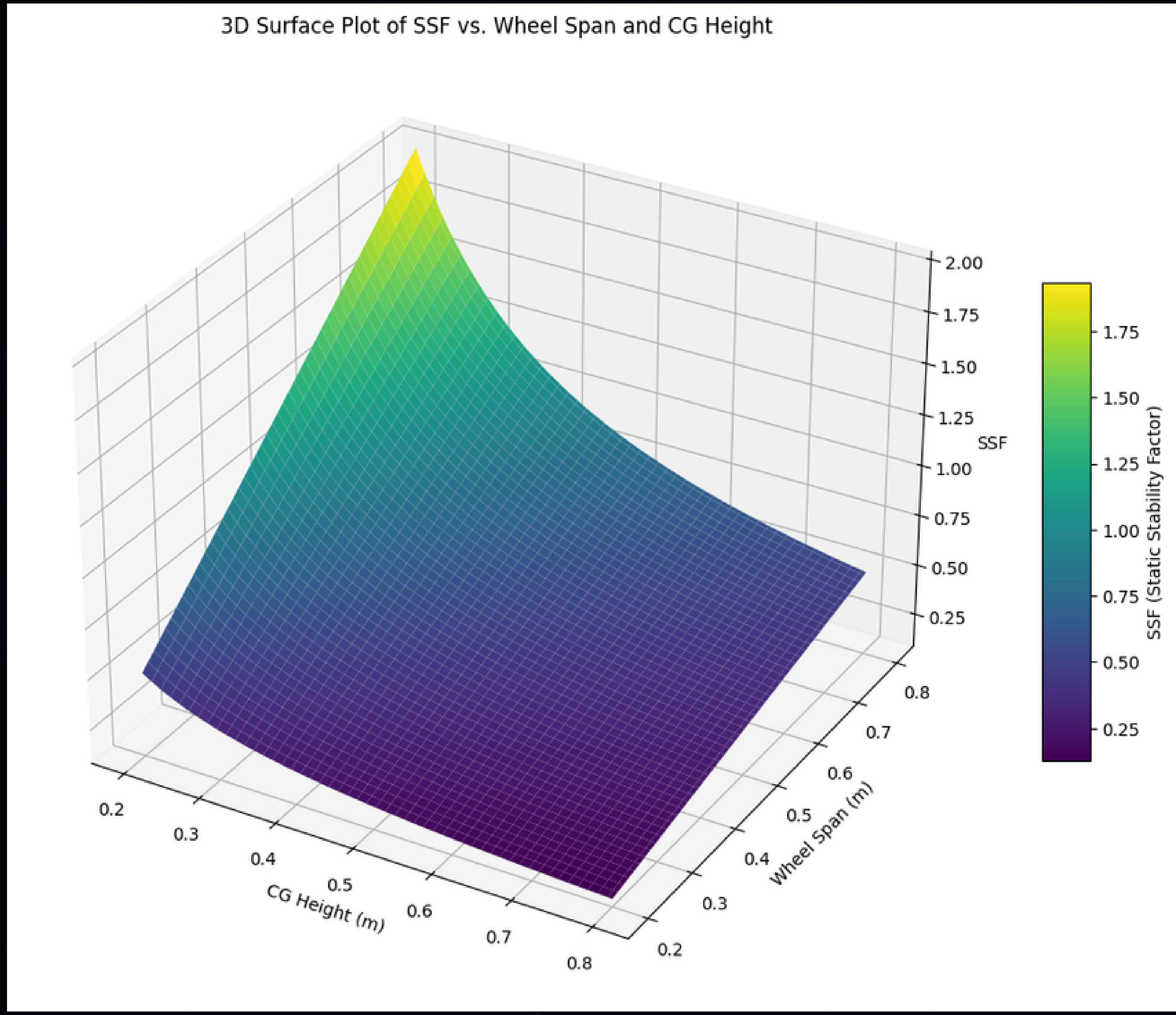
Optimal Wheel Span = 2 m

Optimal Wheelbase = 1.6 m

Optimal CG Height = 0.5 m

OPTIMAL VALUE OF CG & WHEEL SPAN





STABILITY ON SLOPES

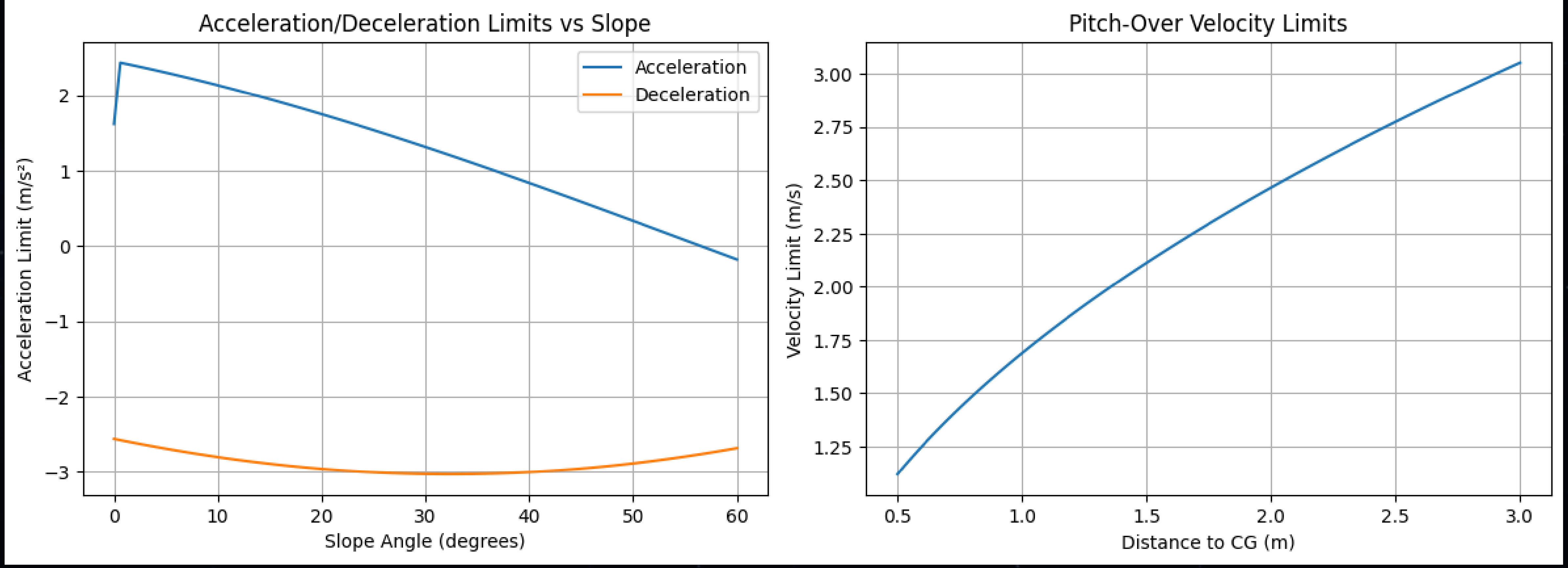
Acceleration Limit Upslope: $$a_{\text{limit}}(\theta) = g\left(\frac{l-a}{h+r}\cos(\theta) - \sin(\theta)\right)$$

Deceleration Limit Upslope: $$a_{\text{limit}}(\theta) = -g\left(\frac{a}{h+r}\cos(\theta) + \sin(\theta)\right)$$

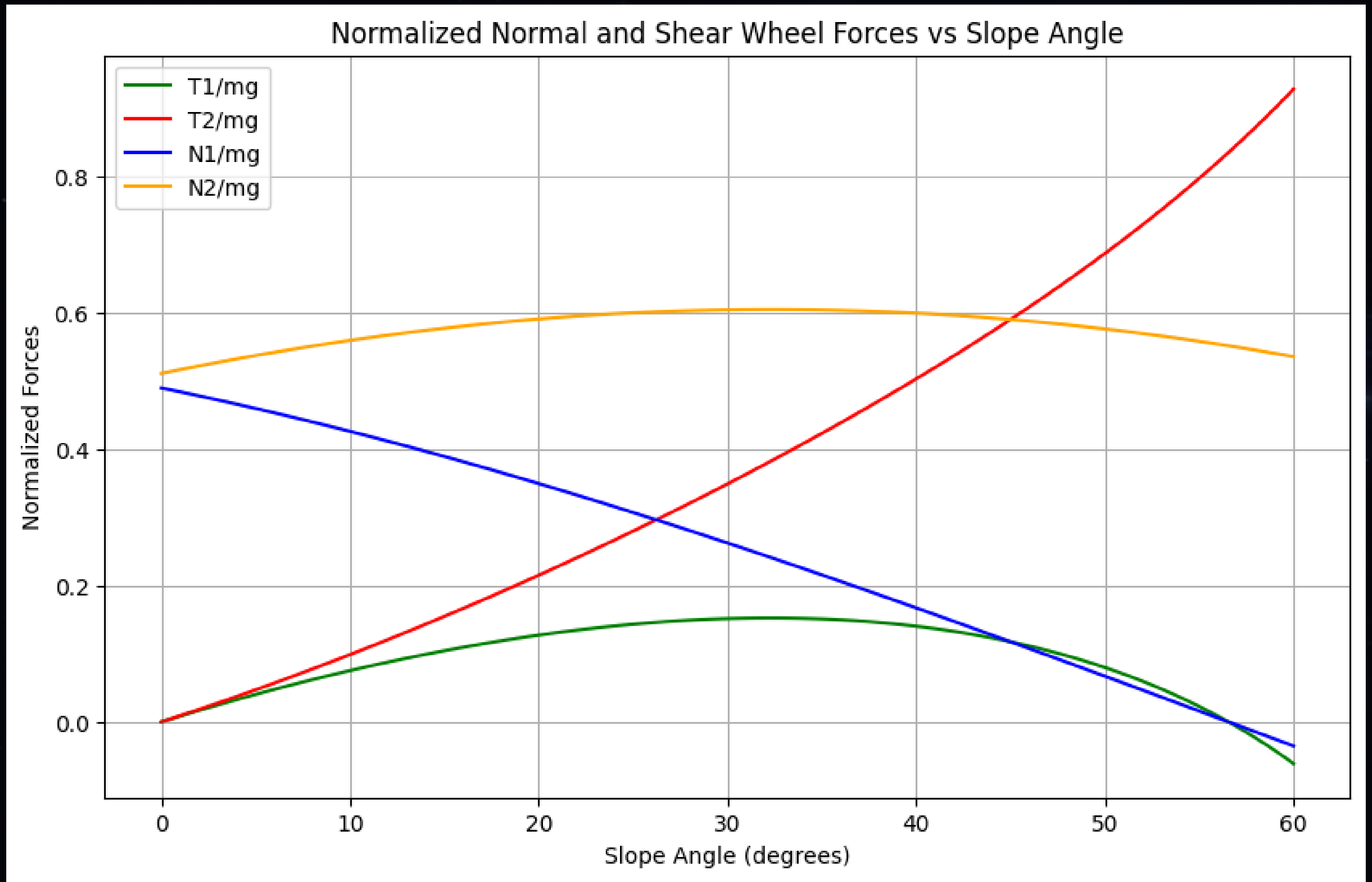
Pitch-over velocity limit (x=2m): 2.46 m/s

Turning radius on slope: $$R_{\text{turn}}(\theta, \frac{y}{h}) = \frac{v^2}{g} \cdot \frac{1}{\frac{y}{h} \cdot \cos(\theta) - \sin(\theta)}$$

Minimum turn radius on 30° slope: 15.18 m



STATIC EQUILIBRIUM FORCES



Force Distribution Behaviour:

At low slope angles:

- Normal forces are nearly equal, as rover’s weight is evenly distributed between the front and rear wheels on flat ground.
- The shear forces are small since the rover isn't moving along the surface

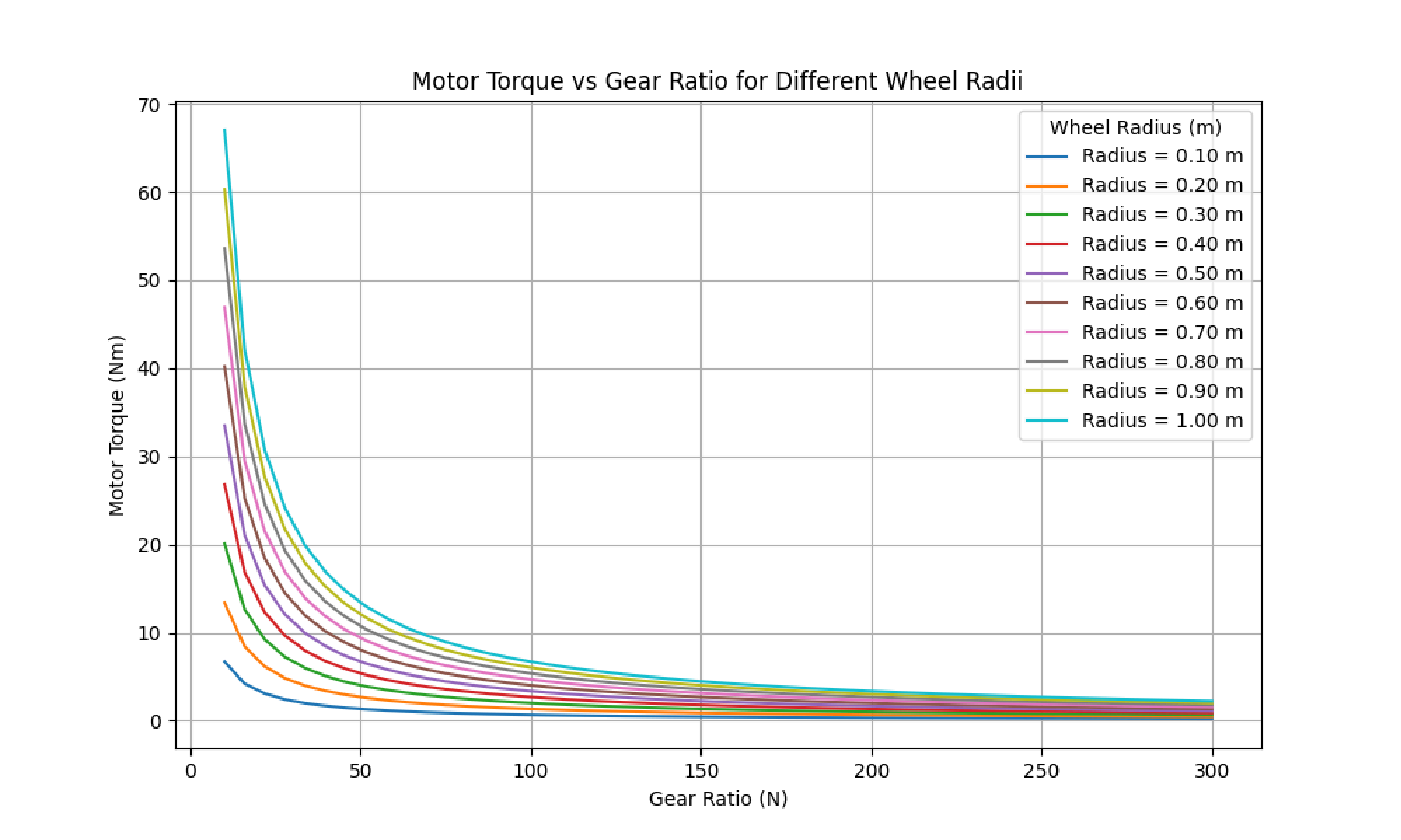
As slope increases:

- The normal forces begin to diverge. As the slope increases, N_1 experiences a larger portion of the normal force due to the change in weight distribution.
- The shear forces increase as the rover starts to resist sliding down the slope.

Near maximum slope angle:

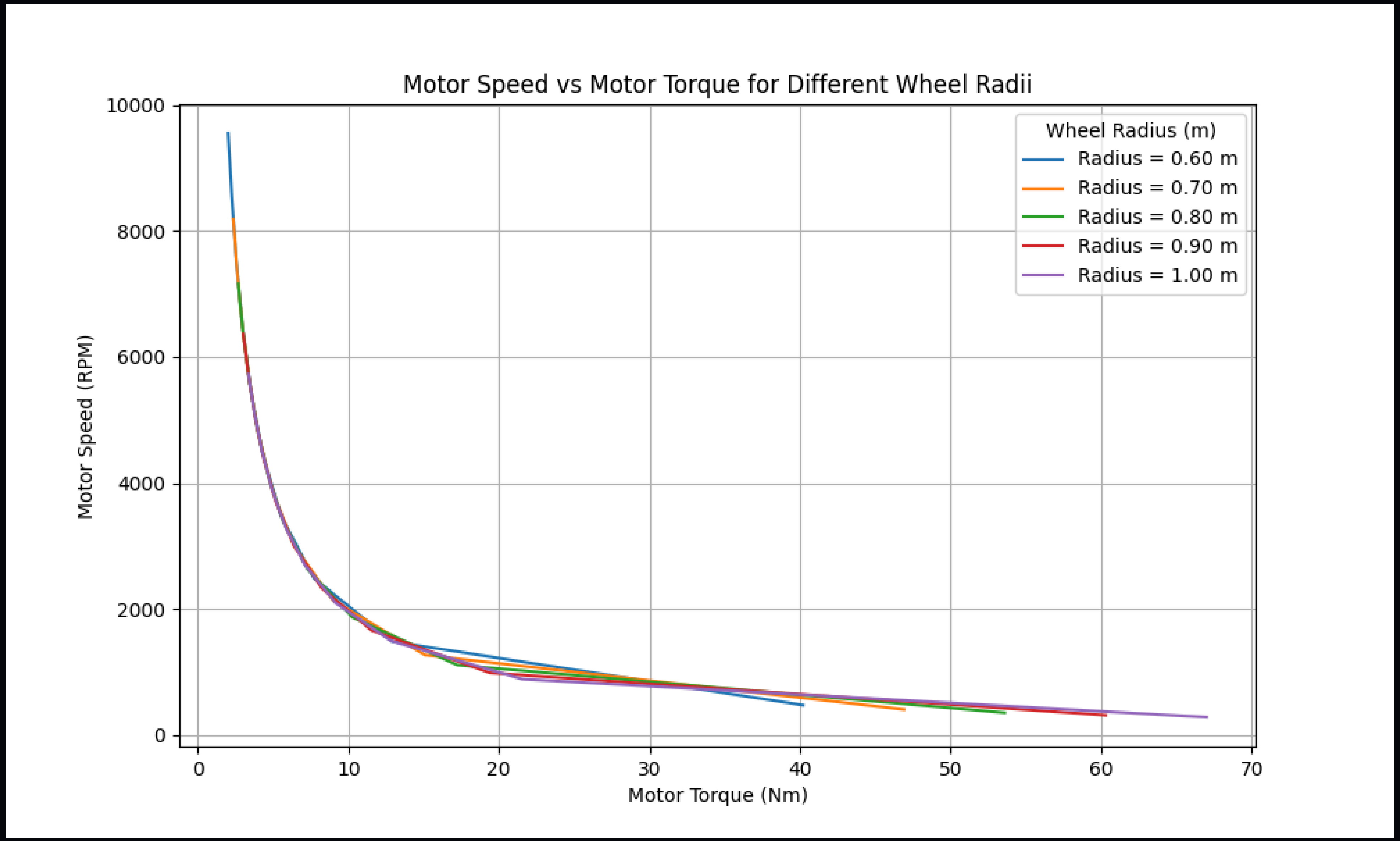
- Rover is close to its static stability limit, will reach instability.

MOTOR TORQUE VS GEAR RATIO



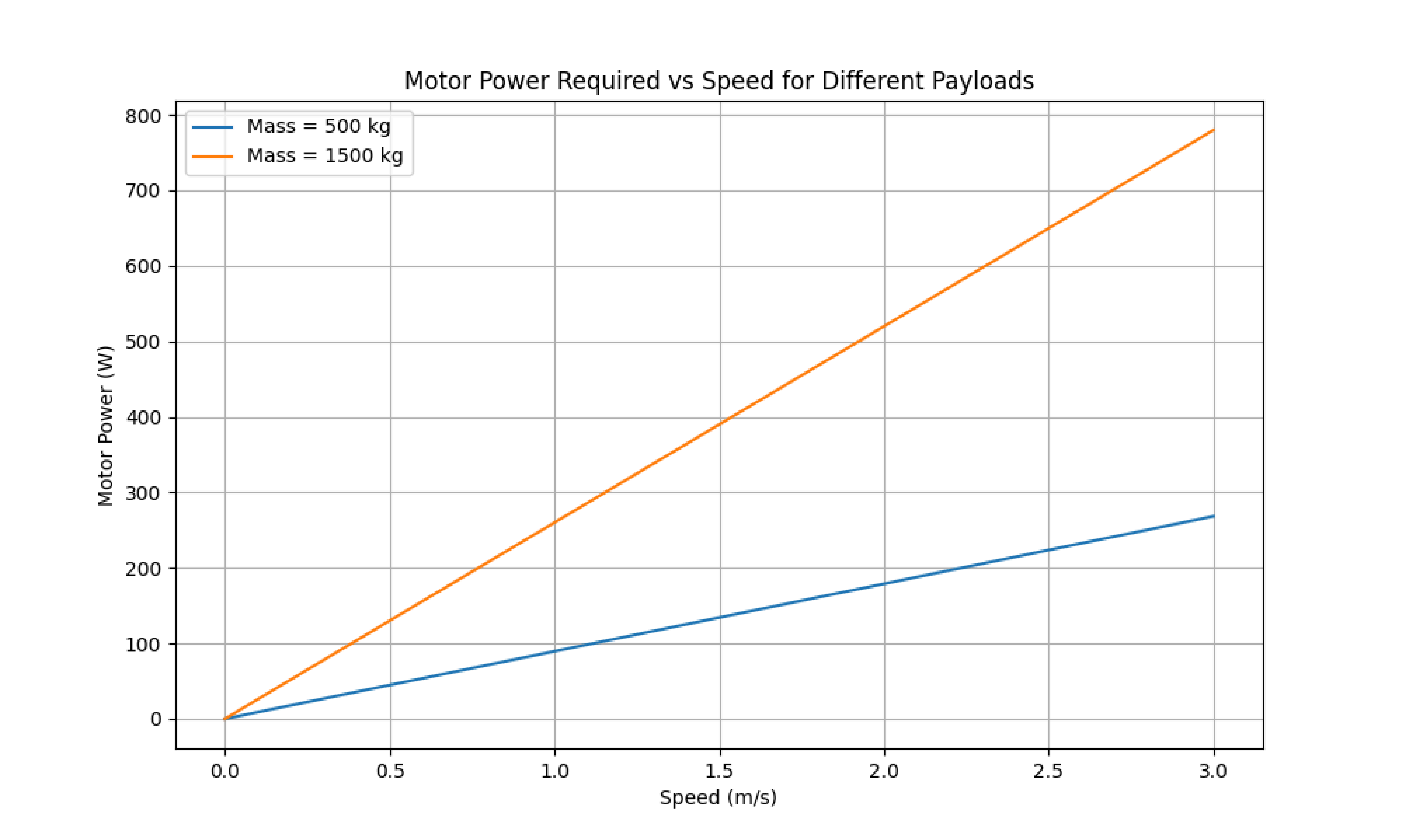
- Larger wheel radius ↣ Higher initial torque
- Higher gear ratio ↣ Reduced required torque
- Our chosen wheel radius: 0.77 m
- Target gear ratio: Balances torque and efficiency for lunar conditions (100:1)
- The Max rolling resistance fora a max slope of 25 degrees and max pay load ~= 1300Nm
- 325Nm per Wheel.

MOTOR TORQUE VS MOTOR SPEED FOR V = 3 m/s

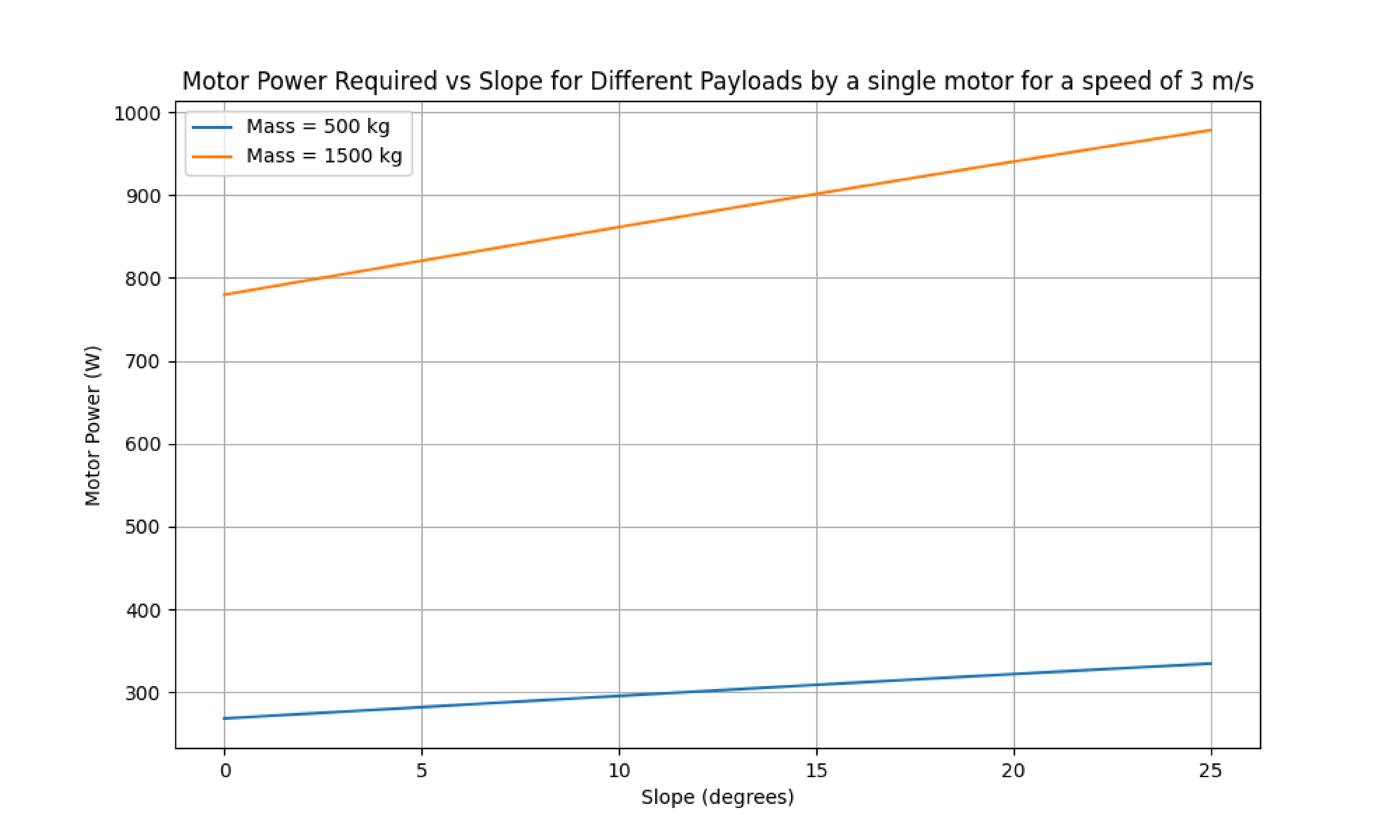


- Motor Speed vs. Motor Torque for Various Wheel Radii
- As wheel radius increases, higher torque is needed at the same speed.
- Increasing torque reduces achievable speed (RPM).
- This helps us find the optimal wheel radius that balances required torque and desired speed.
- For the rover to move at a velocity of 3 m/s the motor RPM should be 4000 with a stall torque being 3Nm

MOTOR POWER VS SPEED

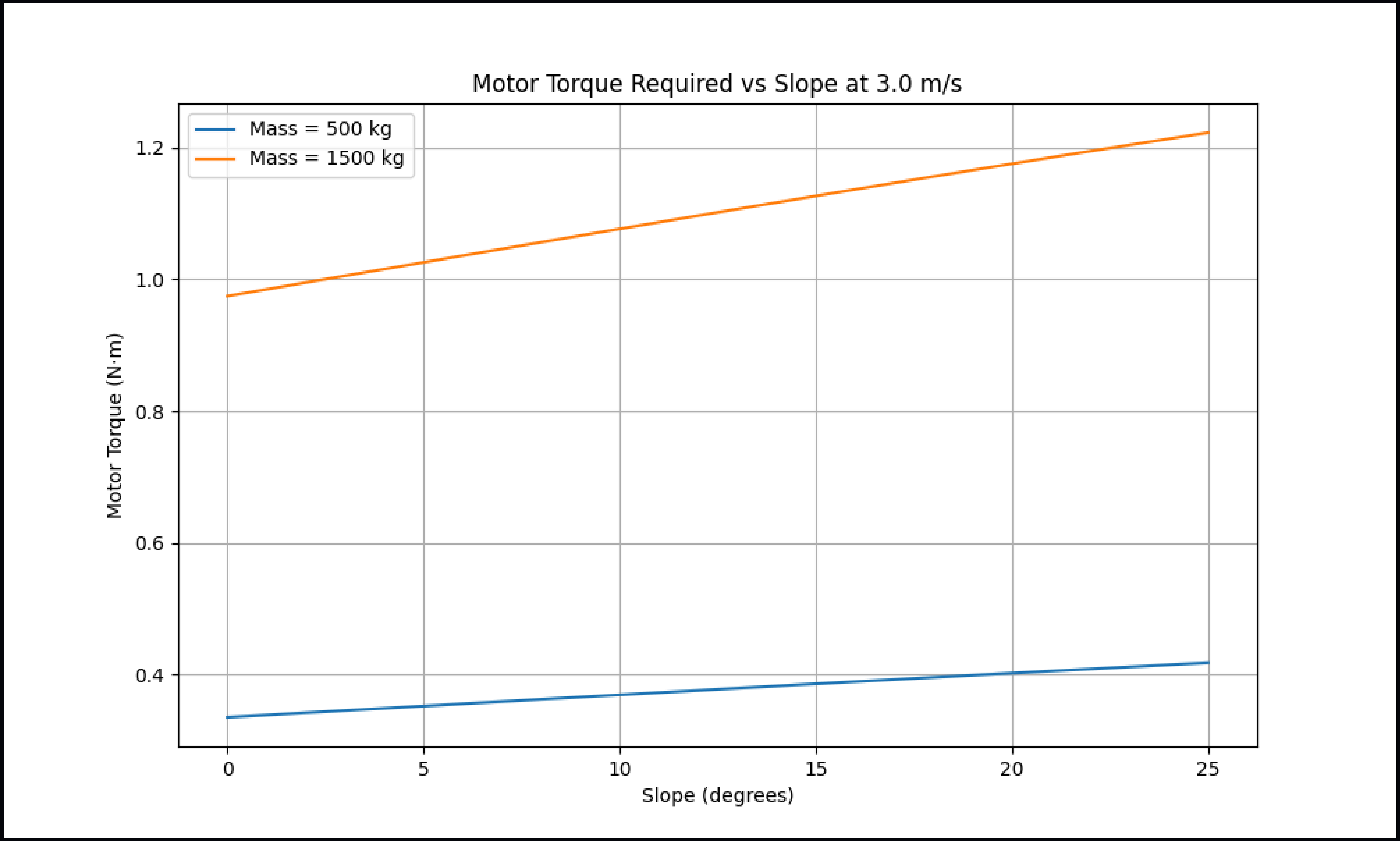


MOTOR POWER VS SLOPE

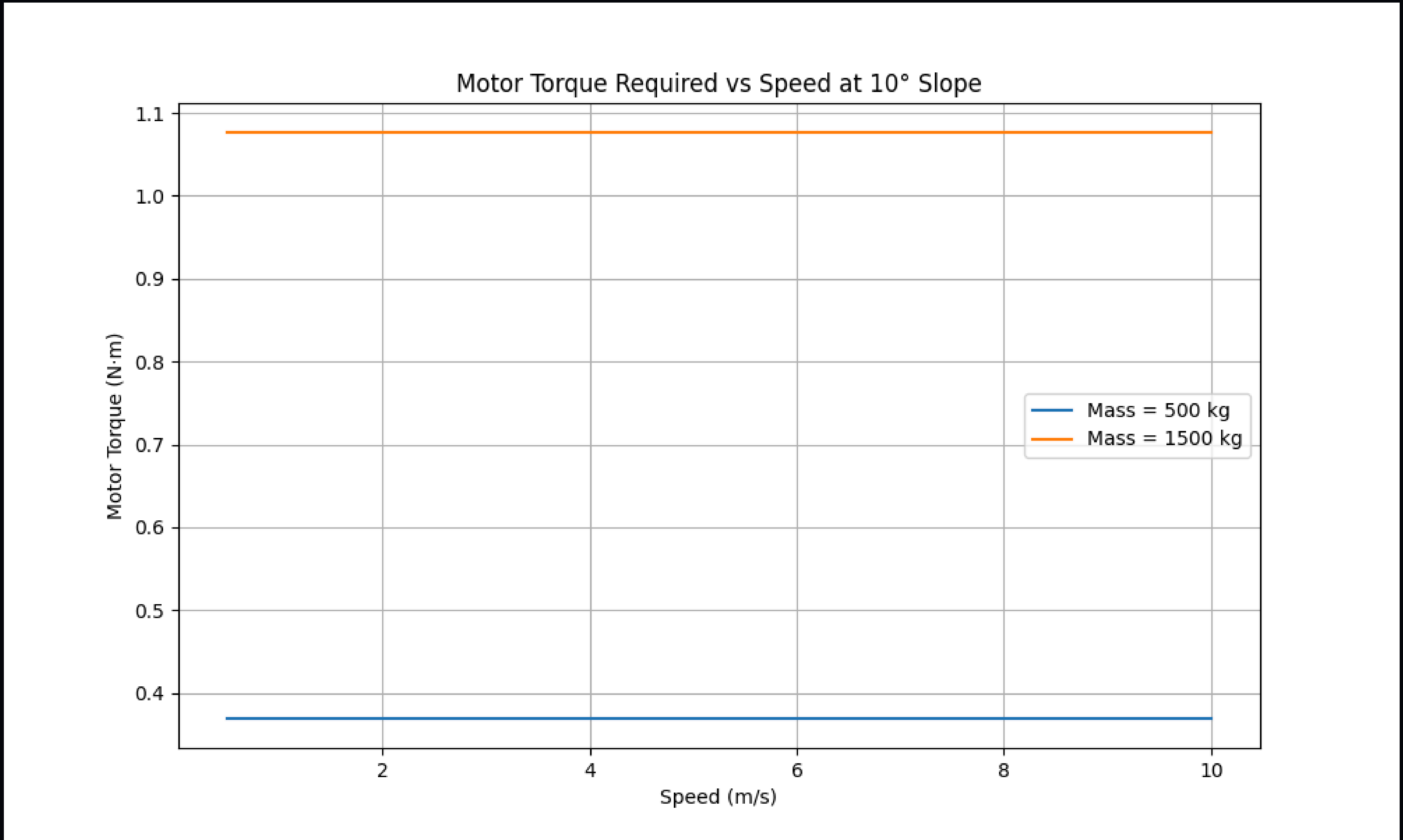


Assuming the rover won’t be climbing a mountain all day, the nominal power used by the motors would be 200W each.

MOTOR TORQUE VS SLOPE



MOTOR TORQUE VS SPEED



Selected Motor & Gear Configuration

MOTOR CHOICE: Kollmorgen AKM Series

- High torque density and efficiency
- Precision servo design for demanding applications

Gear Reduction: 100:1

- Significant torque amplification for improved traction on loose lunar soil
- Lower wheel speed for finer control and stability

Benefits:

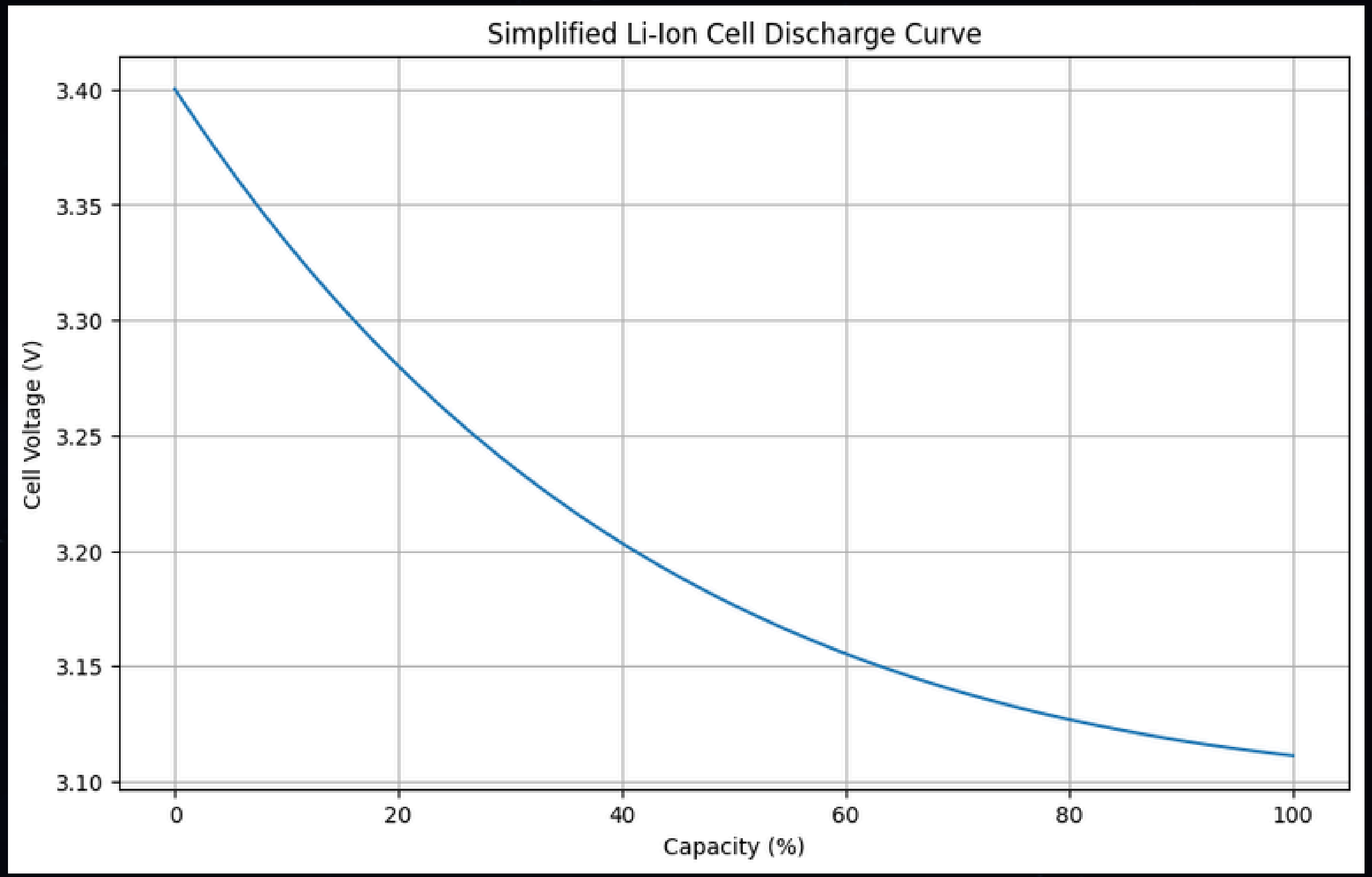
- Enhanced performance under varying loads
- Reduced motor strain and improved energy efficiency
- Modular and scalable approach for future mission adaptability

BATTERY

Lithium-Ion Battery Design

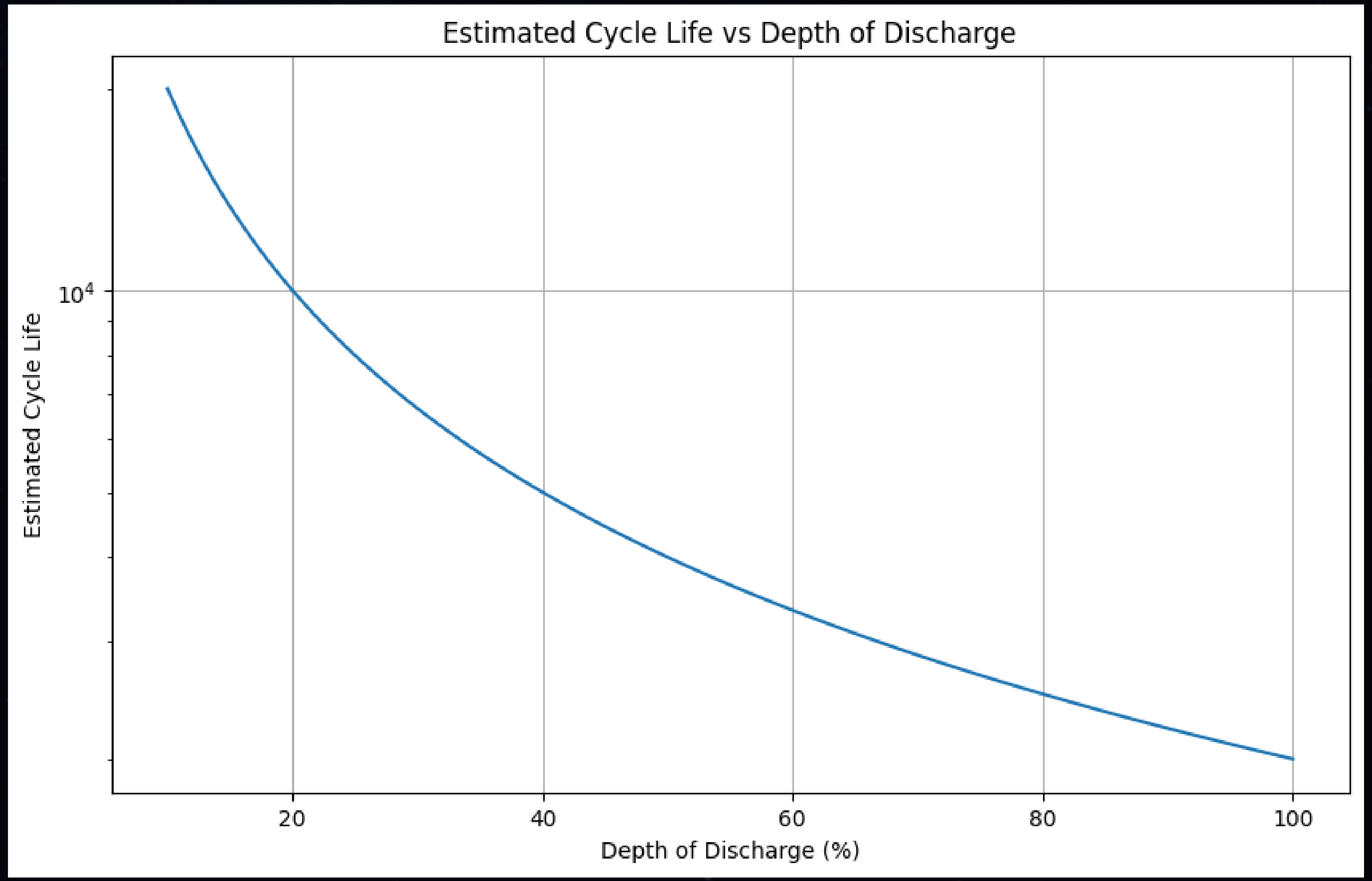
Key Design Parameters:

- Operation Time: 8 hours with 20% margin
- Battery Voltage: 28 V
- Cell Voltage: 3.6 V per cell
- Cell Capacity: 60 Ah
- Energy Density: 125 Wh/kg
- Depth of Discharge: 40% for extended cycle life
- Average Power: 2000 W = 19200 Wh



Design Results

- Battery Capacity: 685.71 Ah
- Number of Cells: 96
- Battery Mass: 19.2 kg
- Energy Density: 125 Wh/kg
- Estimated Cycle Life: 5000 Cycles

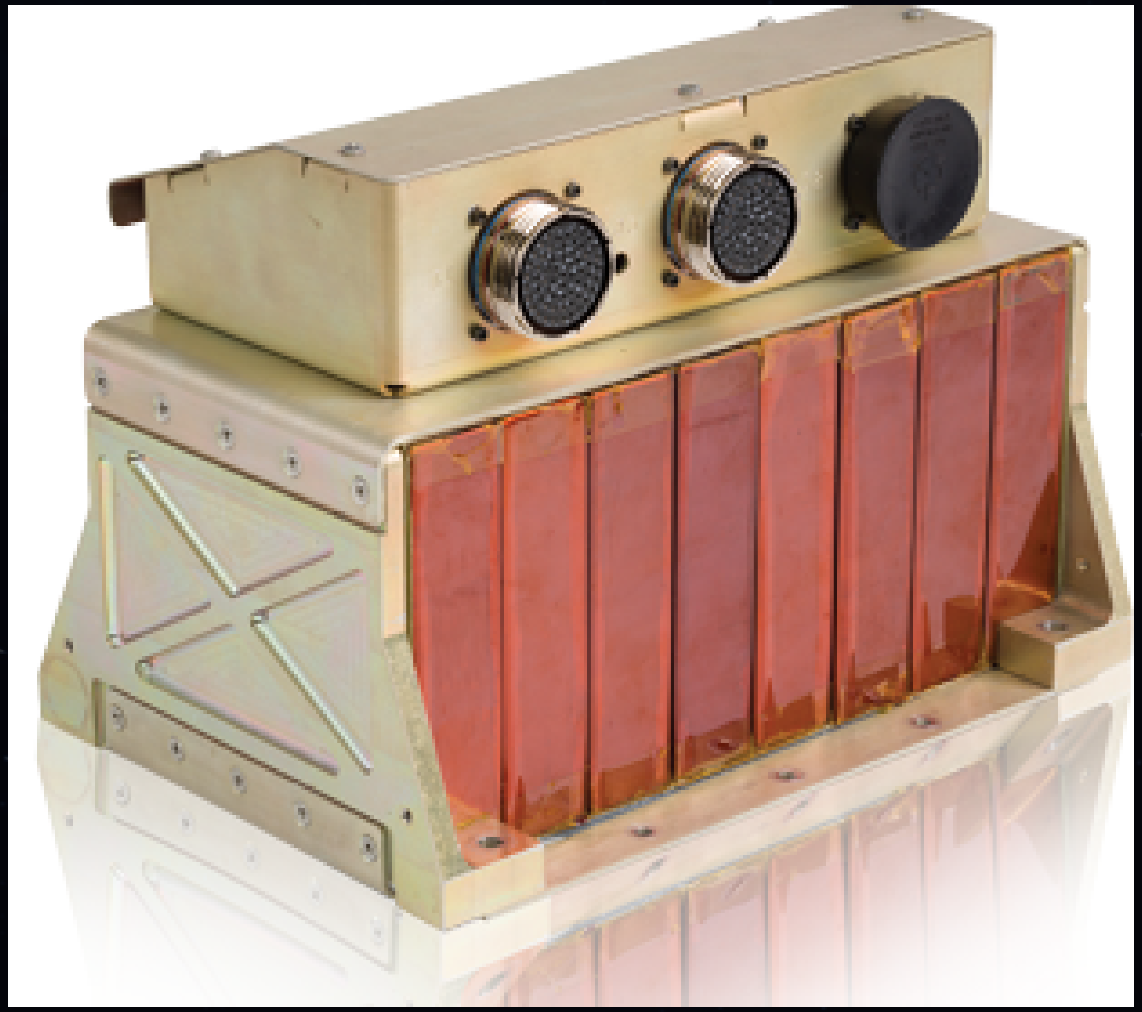


BATTERY

EaglePicher LP 33165 Li-Ion Battery

- Similar Battery to the designed one
- Designed for lunar missions and planetary exploration
- Prioir used in OSIRIS-REx, MAVEN and Juno Mission

Specifications*	
Part Number	LP 33165
Weight	18 kg (40 lbs)
Dimensions	See details on back
Voltage Range	24.0 to 32.8 V
Nominal Voltage	28 V
Nominal Capacity	60 Ah
Energy Density	123 Wh/L
Specific Energy	109 Wh/kg
Discharge Rates	Continuous: 1C
	Pulse: 2C for 1 seconds
Nominal Cell Impedance	2 mΩ at 50% state of charge
Cycle Life (40% depth of discharge 90-minute low-earth orbit cycles)	>40,000
Standard Charging Method	Constant current 12 A (C/5) to 4.1 V
	Constant voltage 32.8 V (4.1 V/cell), taper to 1.2 A (C/50)
Operating Temperature	-20 to 40°C (-4 to 104°F)
Recommended Storage Temperature	0°C ±10°C (32°F ±18°F)



SENSORS

INTEROCEPTIVE SENSORS

Sensor	Specification	Purpose
Inertial Measurement Unit (IMU)	Honeywell HG4930 Accuracy: ±0.01°/hr drift, ±0.02° orientation error Weight: <0.5 kg	Tracks rover orientation and stability
Wheel Encoders	AMS AS5047D Resolution: 14-bit Accuracy: ±0.05°	Measures wheel rotations and actuator motions for mobility control
Current/Voltage Sensors	INA260 Power Monitor Voltage Range: 0-36 V Accuracy: ±0.02%	Monitors power usage for operational safety and efficiency

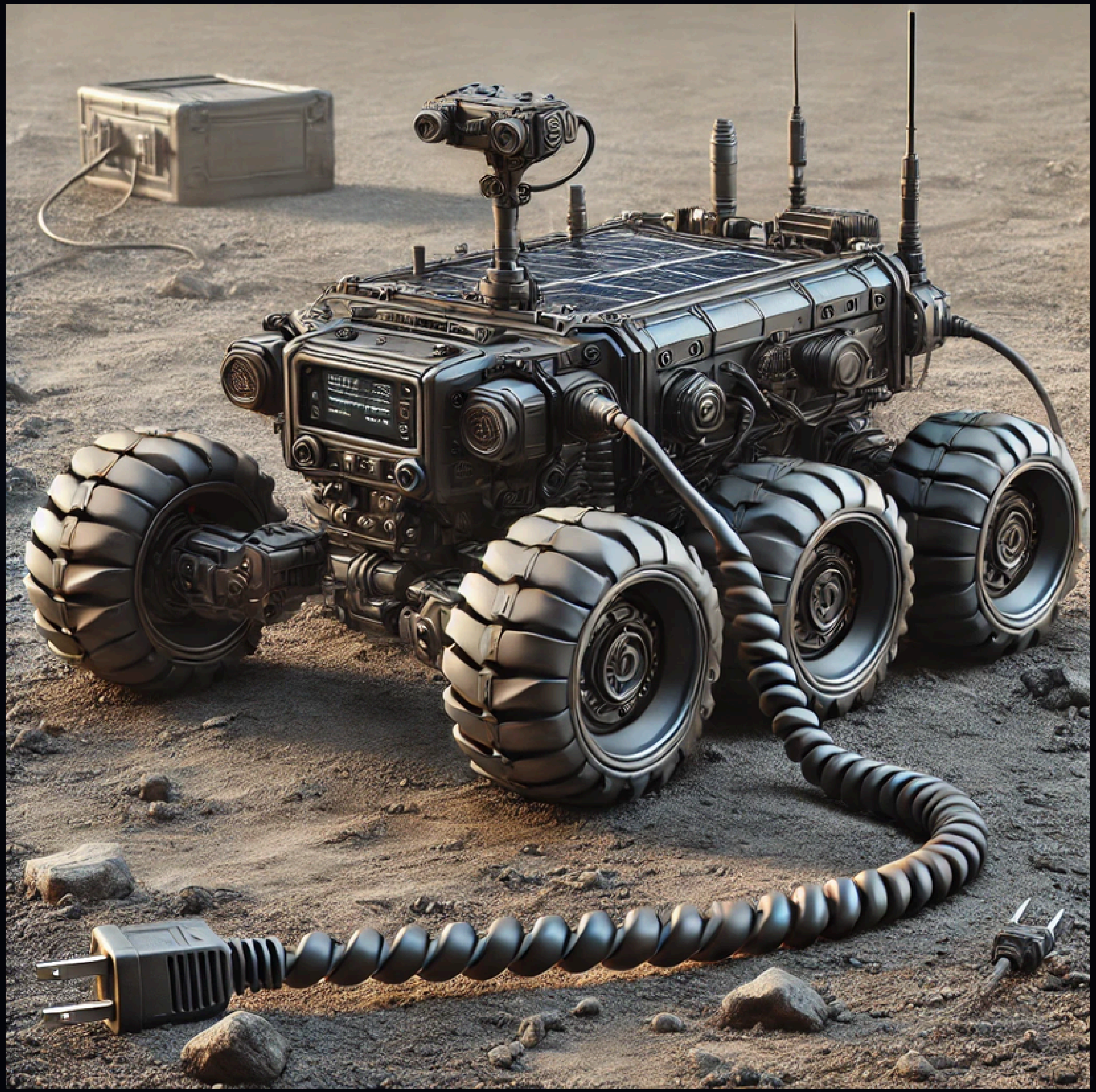
SENSORS
EXTEROCEPTIVE SENSORS

Sensor	Specification	Purpose
LiDAR	Velodyne VLP-16 Range: 100m Accuracy: ±3 cm Weight: 0.83 kg	Enables 3D mapping and obstacle avoidance
Stereo Cameras	Intel RealSense D455 Resolution: 1280x800 Range: 6-10 m Weight: 0.33 kg	Provides depth perception for terrain mapping
Thermal Camera	FLIR Boson Resolution: 640x512 Weight: 0.07 kg	Detects temperature anomalies and surface features
Sun Sensors	Adcole Sun Sensor Accuracy: ±0.5°	Provides orientation relative to the sun for navigation

SELF-CONNECTION TO RECHARGER

Autonomous Docking

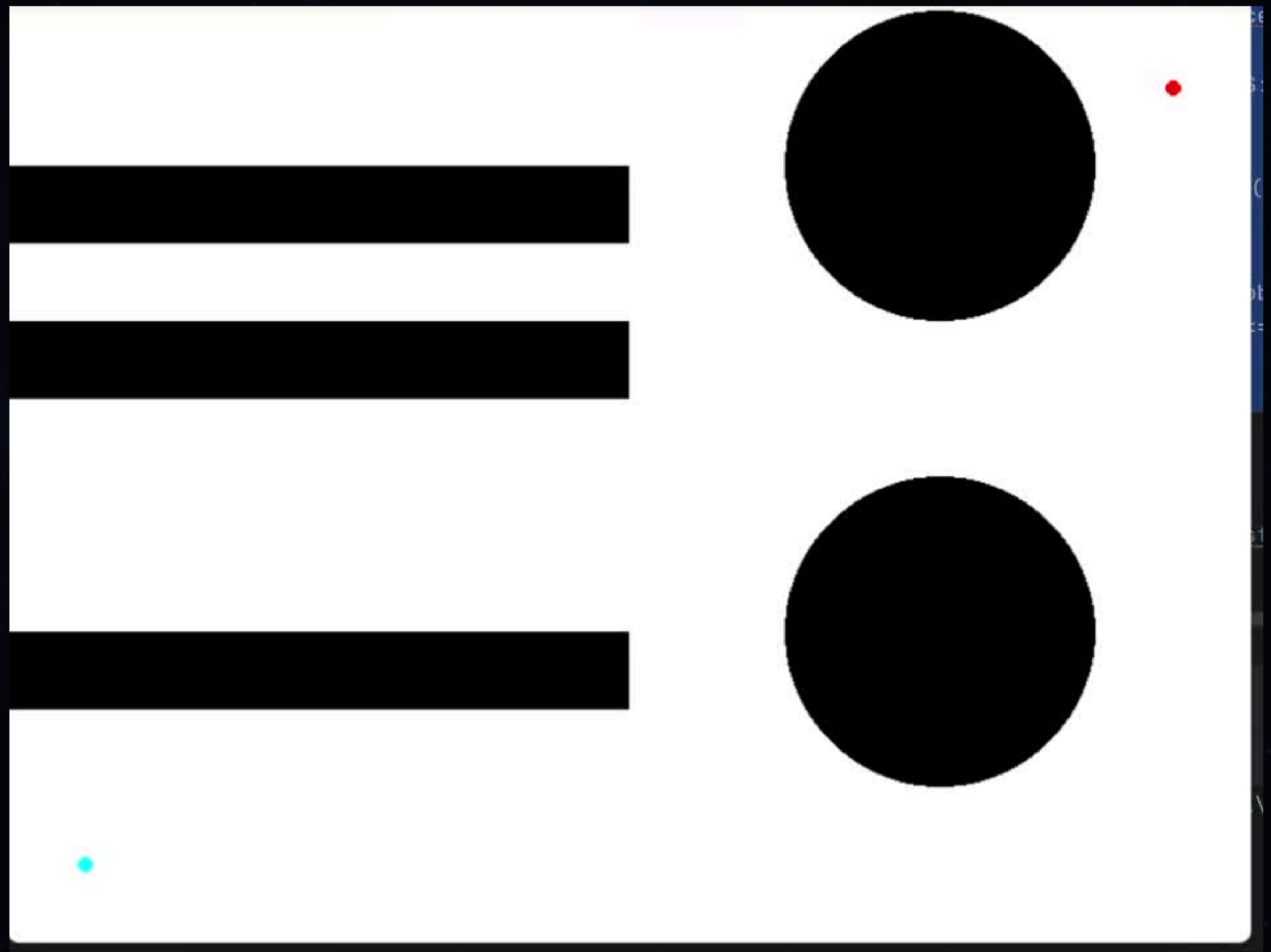
- Intel Realsense D455 Stereo camera is used for detecting and localizing the position and orientation of the charging port.
- Use physical connectors with alignment guides to ensure a robust connection.
- Include retractable charging arms on the LLUV.



PATH PLANNING

Recommended Path Planning Algorithm: MOD-RRT*
Why MOD-RRT*:

- Global Path Planning: Handles complex terrain with obstacles efficiently.
- Collision-Free Paths: Ensures safe traversal in uneven terrain.
- Advantages Over A*: Can manage dynamic and non-linear constraints better, making it ideal for the unpredictability of extraterrestrial terrains.



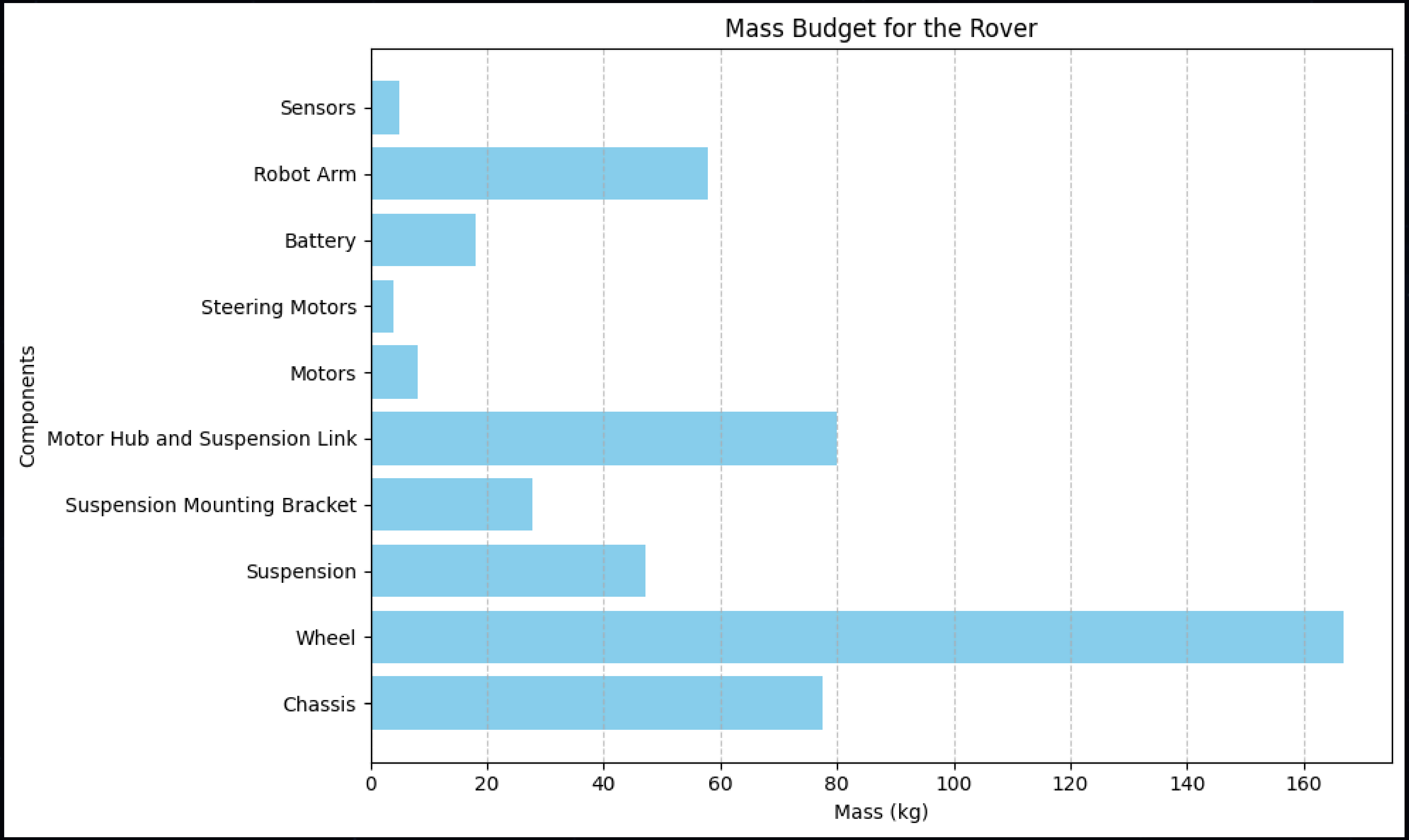
Implementation Steps:

1. Use LiDAR and stereo cameras to create a 3D map of the environment.
2. Implement MOD-RRT* to generate an optimized path from the rover's position to its destination.
3. Continuously update the map and refine the path using sensor feedback for dynamic obstacle avoidance.

MASS BUDGET

Component	Mass
Chasis	77.64 kg
Wheel	41.7 x 4 kg
Suspension	11.8 x 4 kg
Suspension Mounting Bracket	13.9 x 2 kg
Motor Hub and Suspension Link	20 x 4 kg
Motors	2 x 4 kg
Steering Motors	1 x 4 kg
Battery	18 kg
UR-10 Robot arms	28.9 x 2 kg
Sesnors	~ 5 kg
Total Mass	492.24 kg

MASS BUDGET

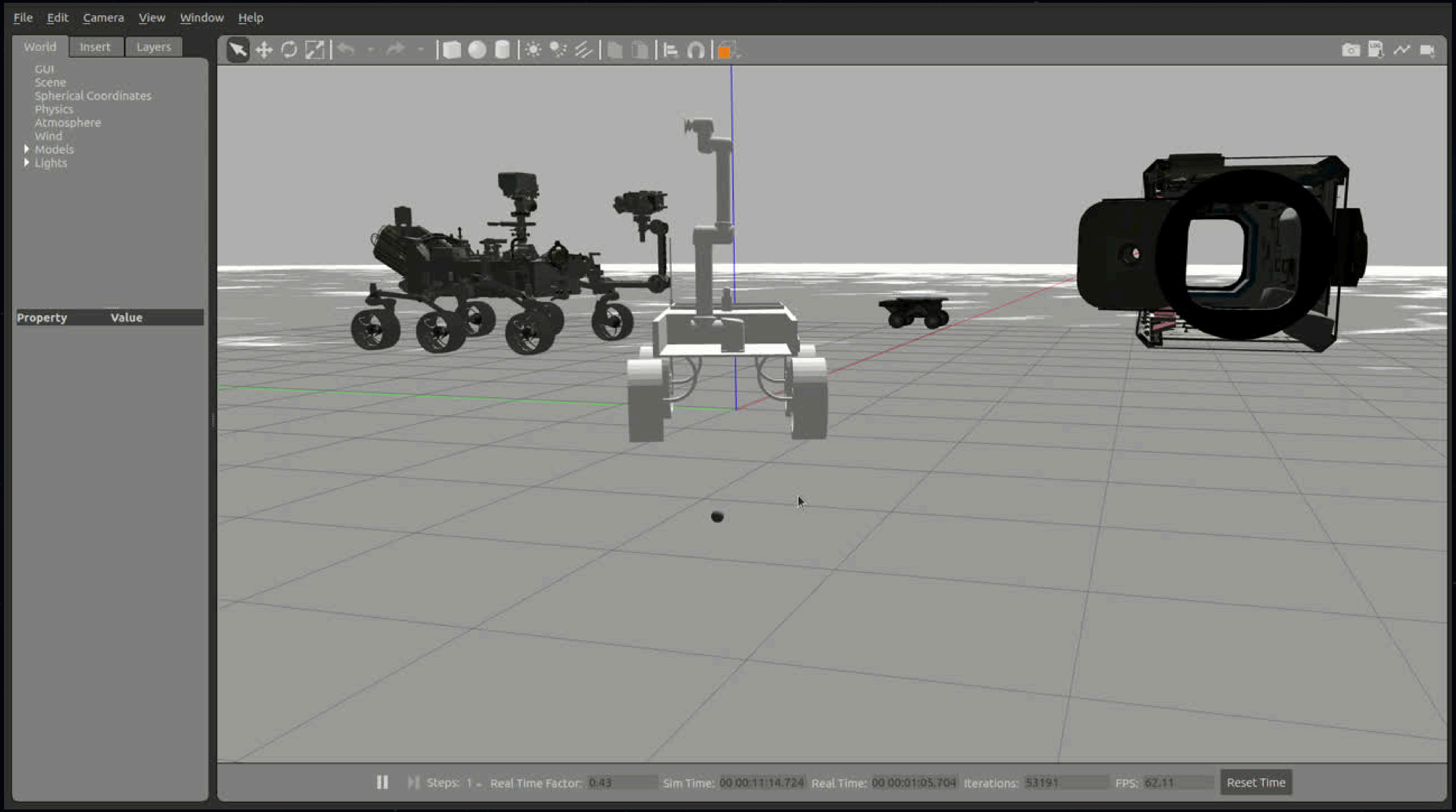


Mass Budget for the Rover
Sensors
Robot Arm
Battery
Steering Motors
Motors
Motor Hub and Suspension Link
Suspension Mounting Bracket
Suspension
Wheel
Chassis
Components
0
20
40
60
80
100
120
140
160
Mass (kg)

AUTONOMOUS CAPABILITIES

1. Teleoperation:
    - The rover can be operated manually using keyboard commands, providing precise control during complex tasks.
2. Autonomous Navigation:
    - Commands are sent to the velocity and position controllers to navigate the rover autonomously to specific points.
3. Sample Collection:
    - The rover is equipped with vacuum grippers for collecting samples autonomously.
4. Mission Execution:
    - The rover autonomously travels to the specified sample locations.
    - After collecting the samples, it returns to the base station, completing the mission cycle.

AUTONOMOUS CAPABILITIES



Video Link

CLPS LANDER

Astrobotic griffin lander

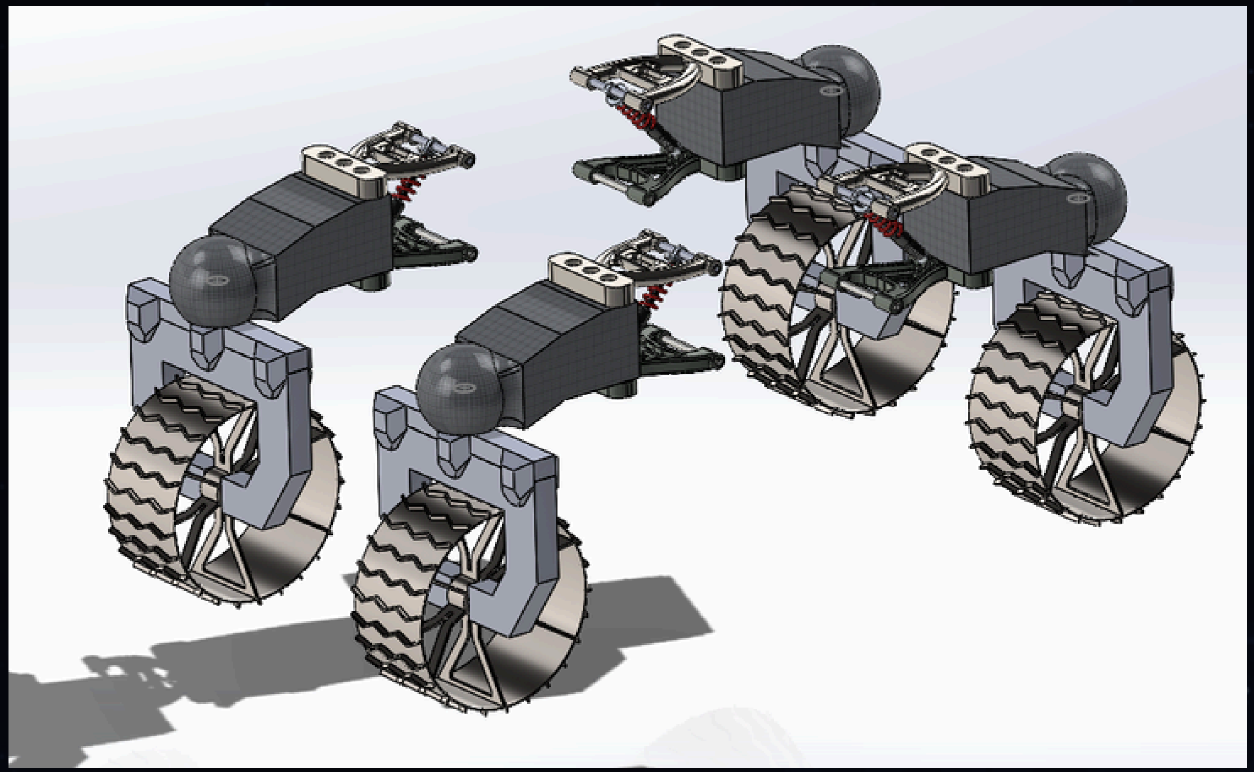
Designed LLUV OF 493 kg, 2.6 x 2.3 x 0.79 cubic meter fits within the Griffin's payload capacity and volume constraints with minor adjustments, making it suitable for direct delivery.

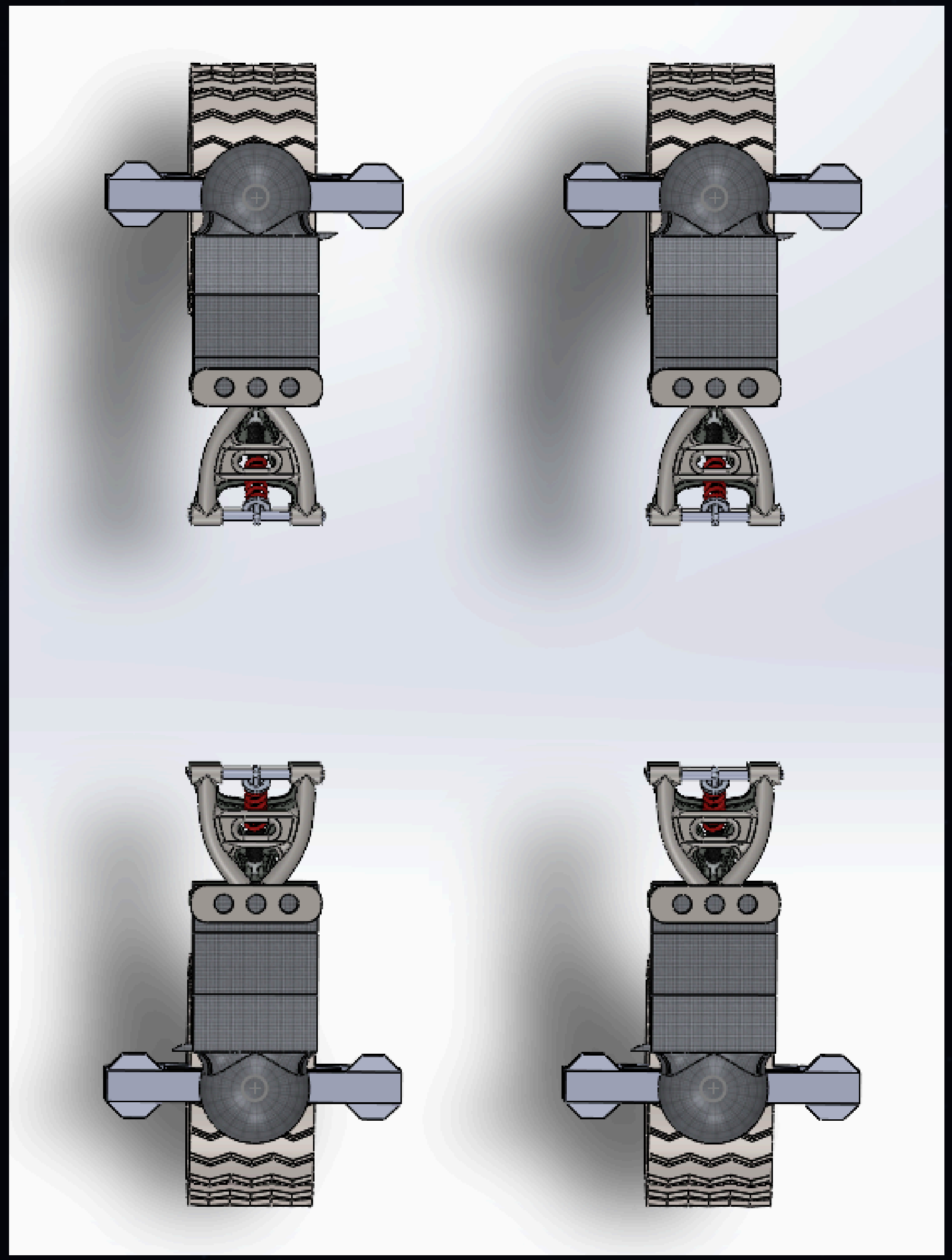
Equipping LLUV with thermal insulation and active heating elements, especially for batteries and sensitive electronics.

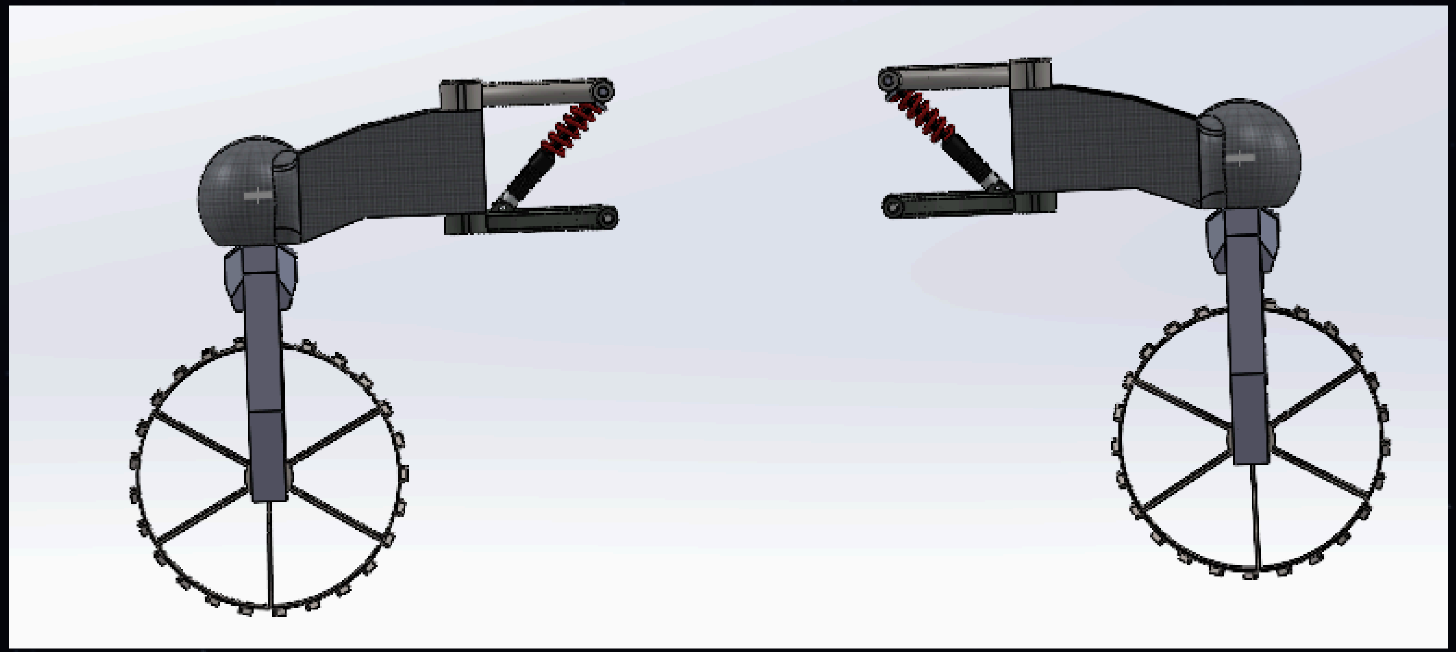
Griffin can provide power to payloads (200 - 1000 W) during transit or on the lunar surface.

Specification	Value
Payload capacity	Up to 500 kg
Payload volume	Approx 4 m^3
Payload Bay Dimensions	Approx. 2.3 m x 1.8 m x 1.25 m
Deployment Mechanisms	Custom ramps, robotic arms, and winches
Environment Tolerance	Thermal: -180°C to +120°C
Power System	200 W to 1000 W power available for payload
Vibration Tolerance	Compatible with lunar payload launch standards

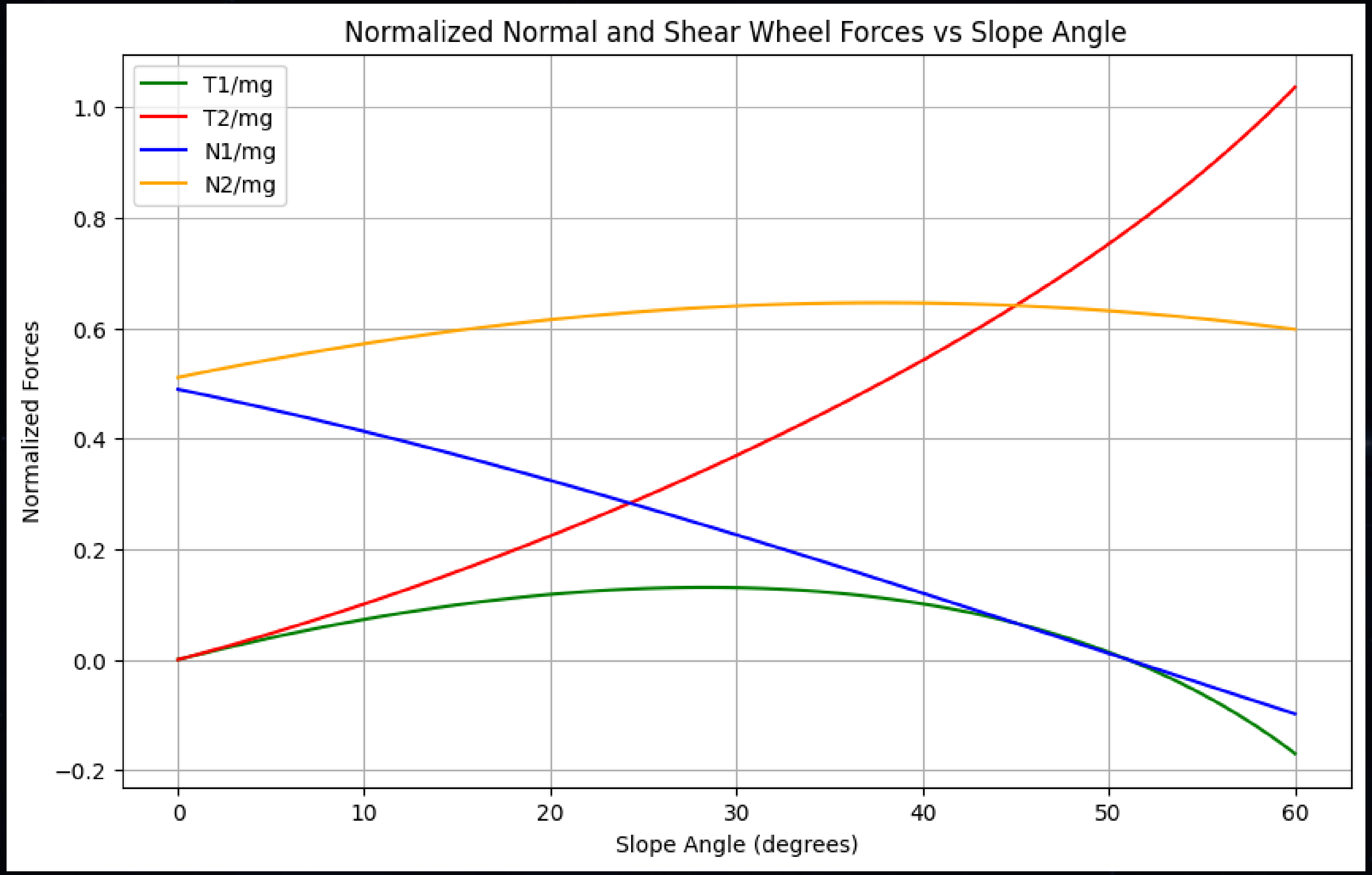
ALTERNATE CONCEPTS



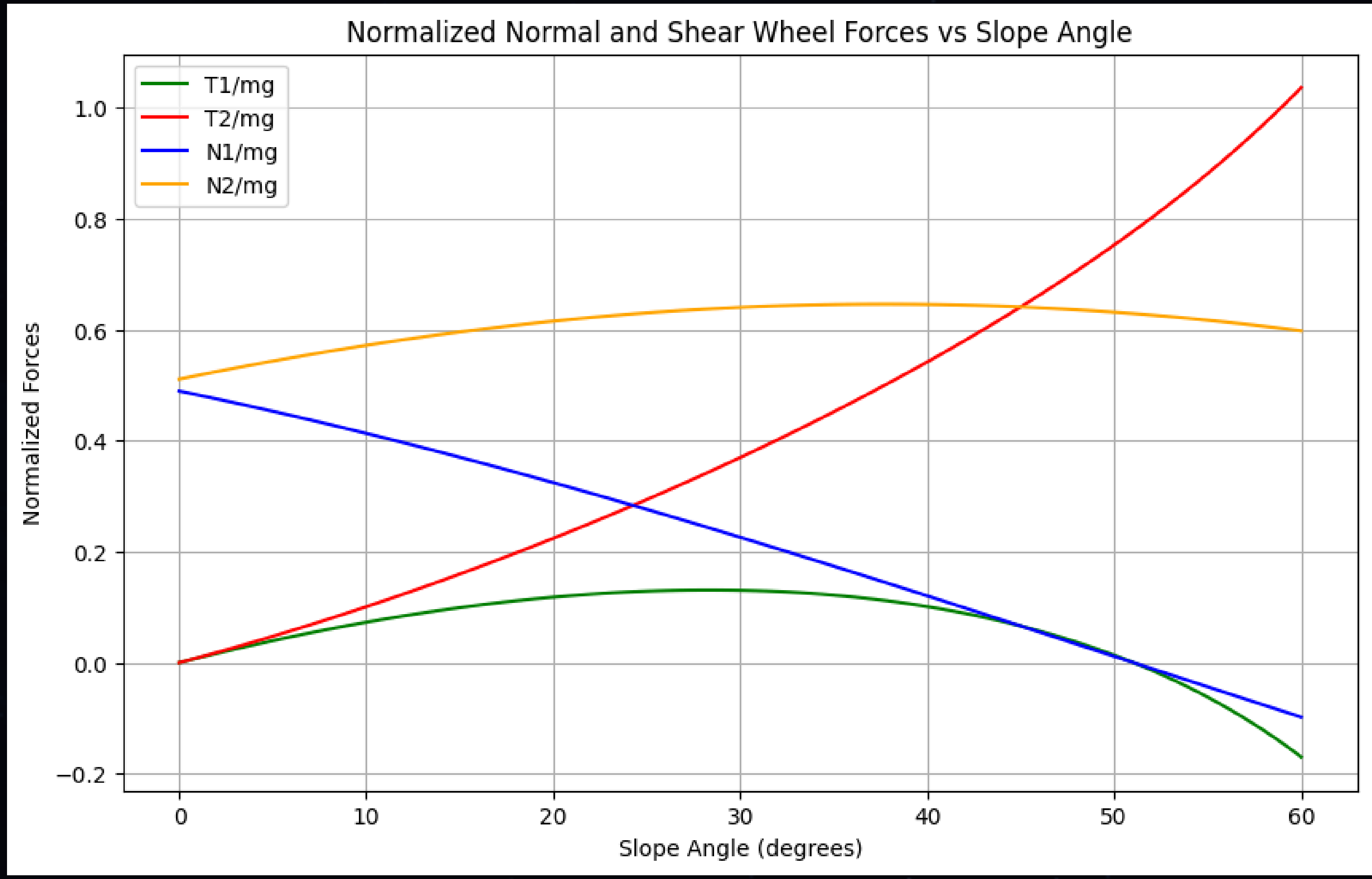




DESIGN FOR MARS & EARTH

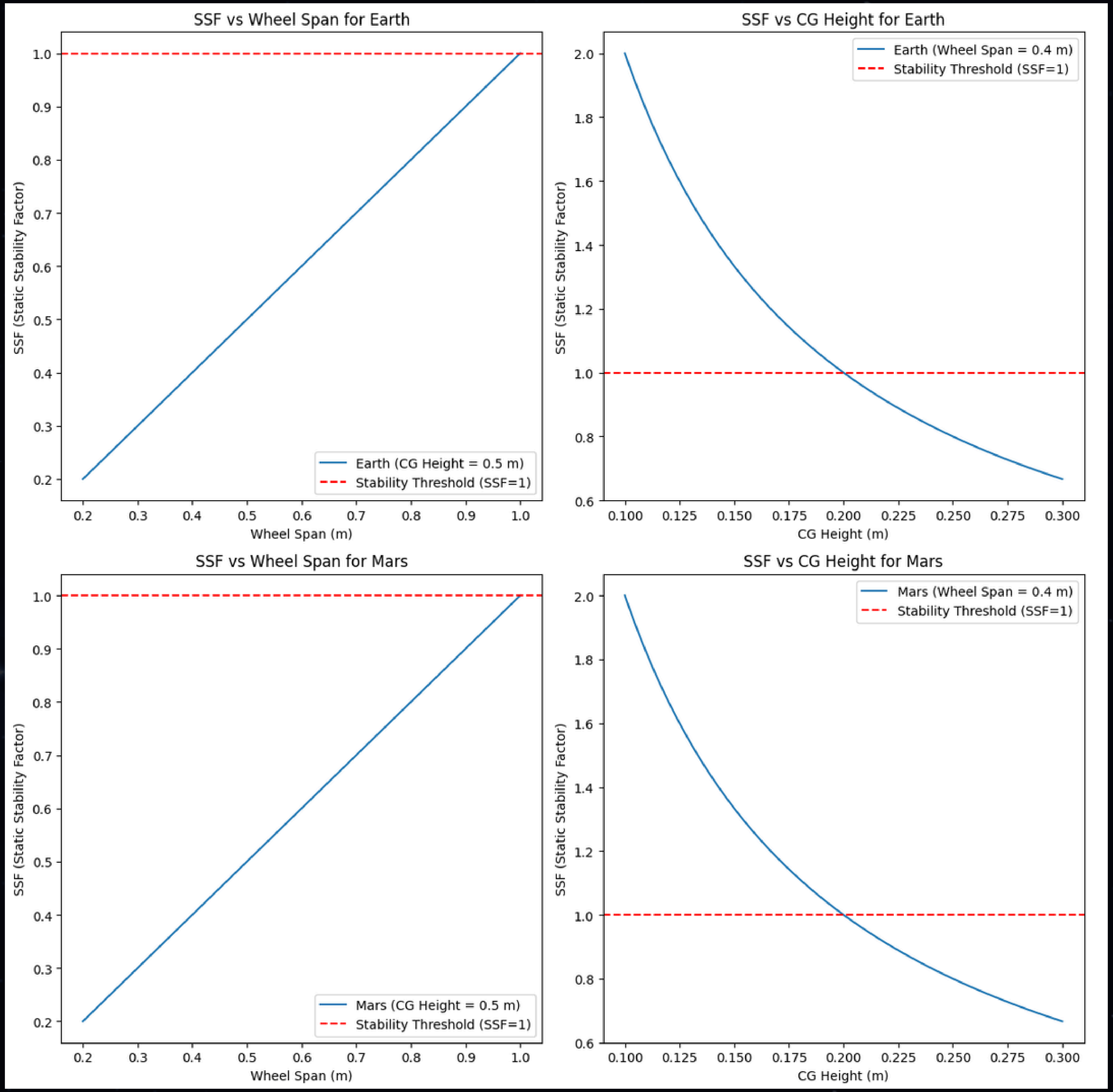


Earth

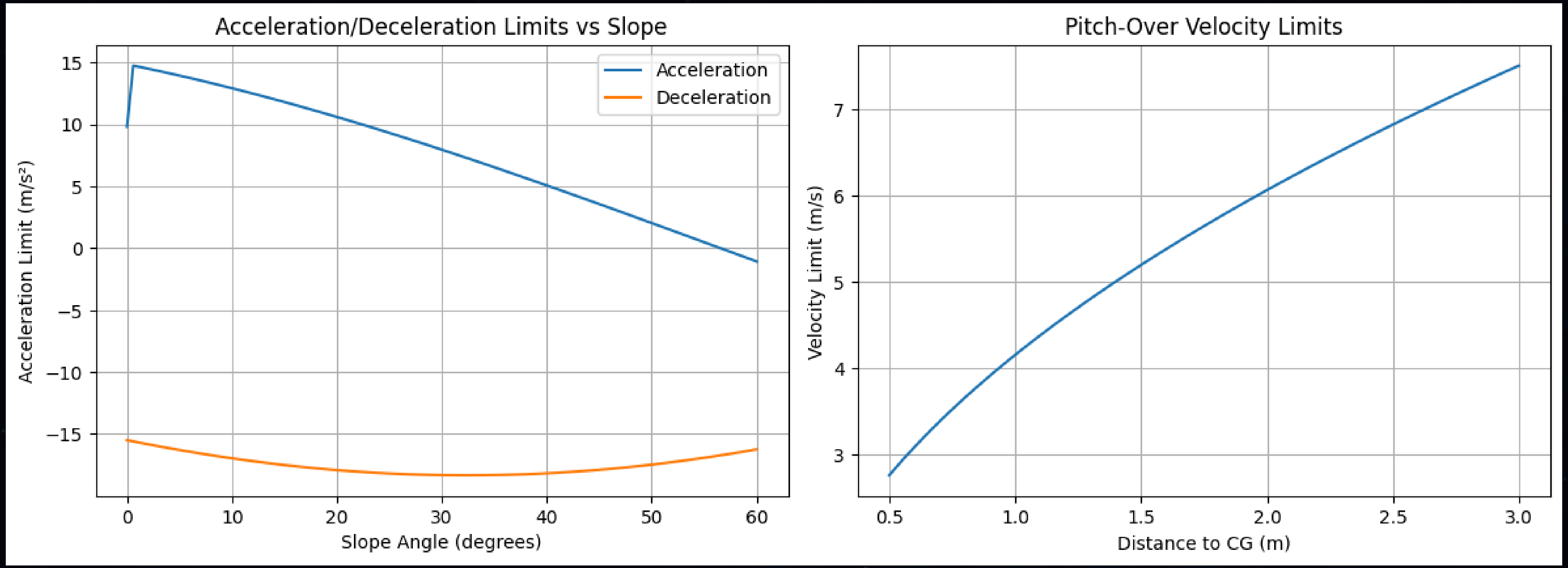


Mars

STABILITY ANALYSIS FOR EARTH & MARS



STABILITY ON SLOPES



Earth

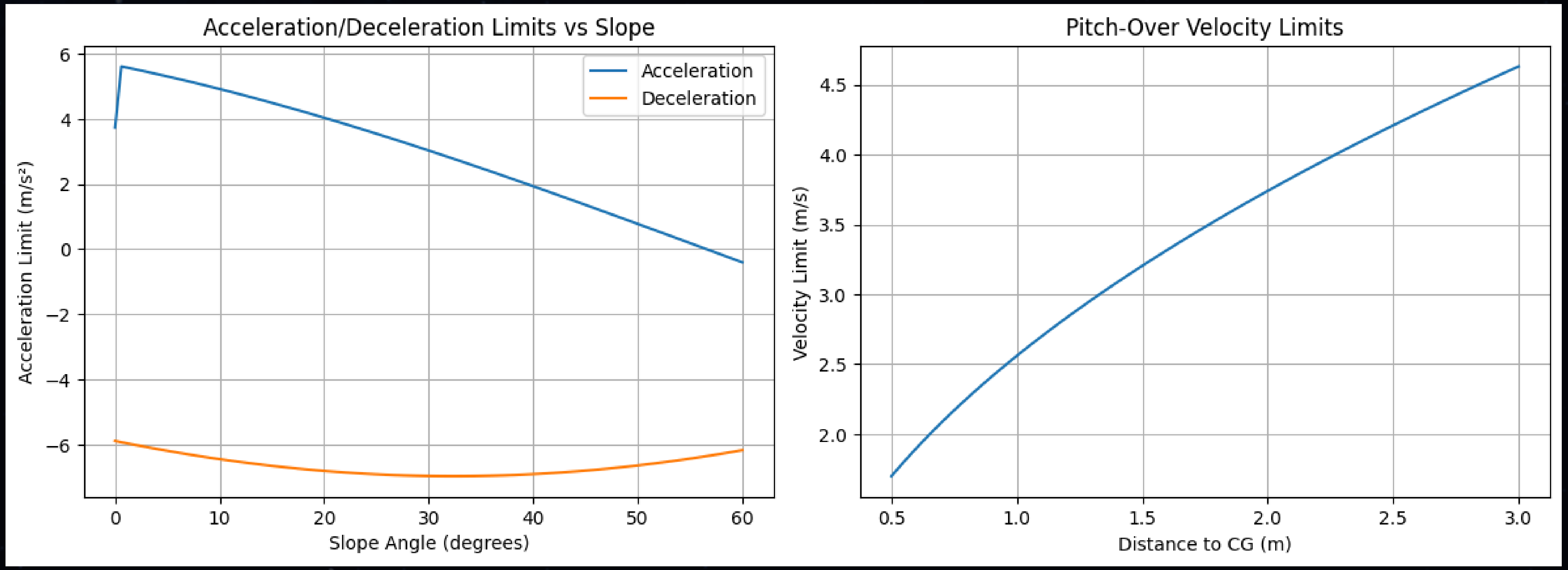
Minimum turn radius on 30° slope: 2.51 m

Pitch-over velocity limit: 6.07 m/s

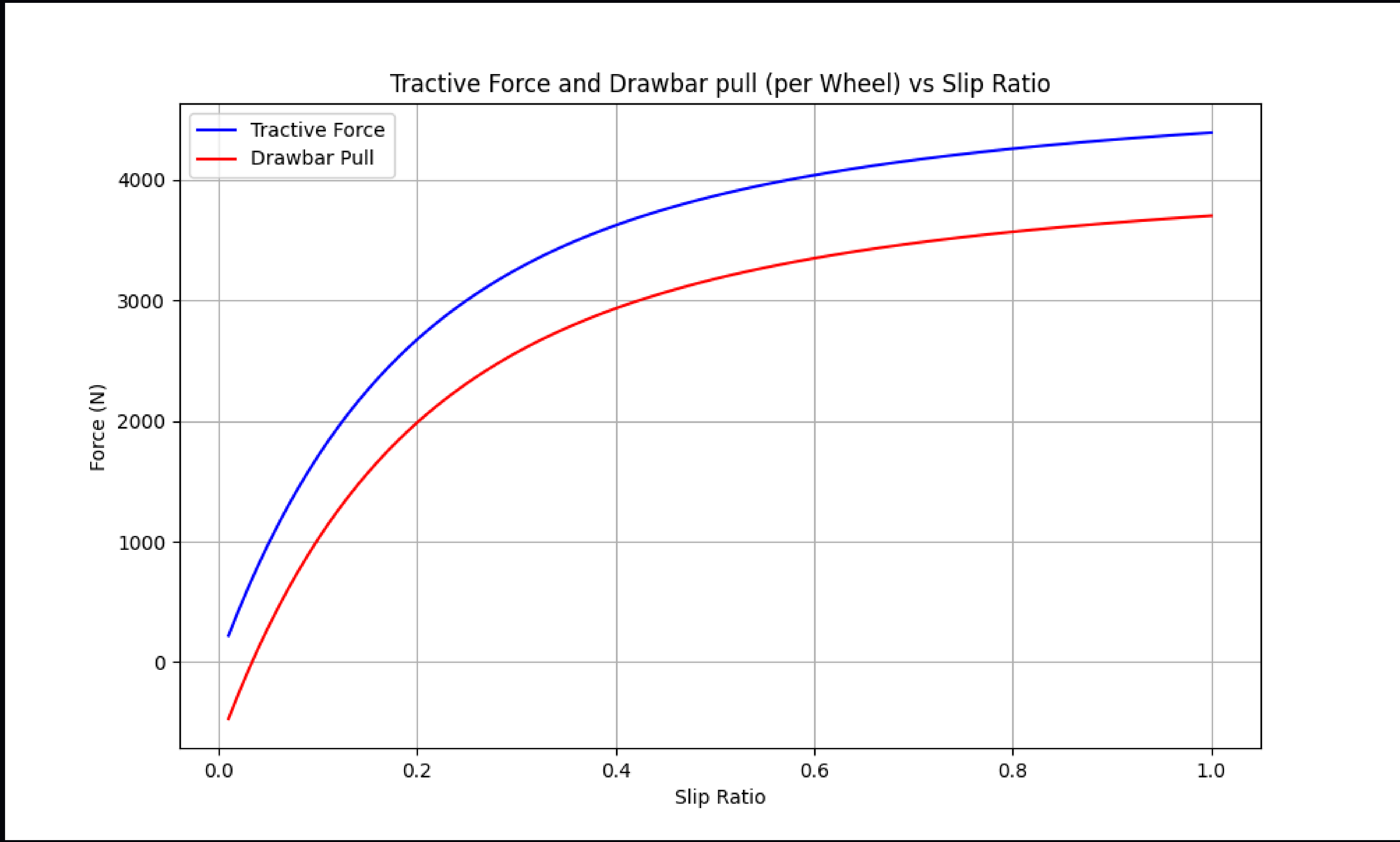
Mars

Minimum turn radius on 30° slope: 6.59 m

Pitch-over velocity limit: 3.74 m/s



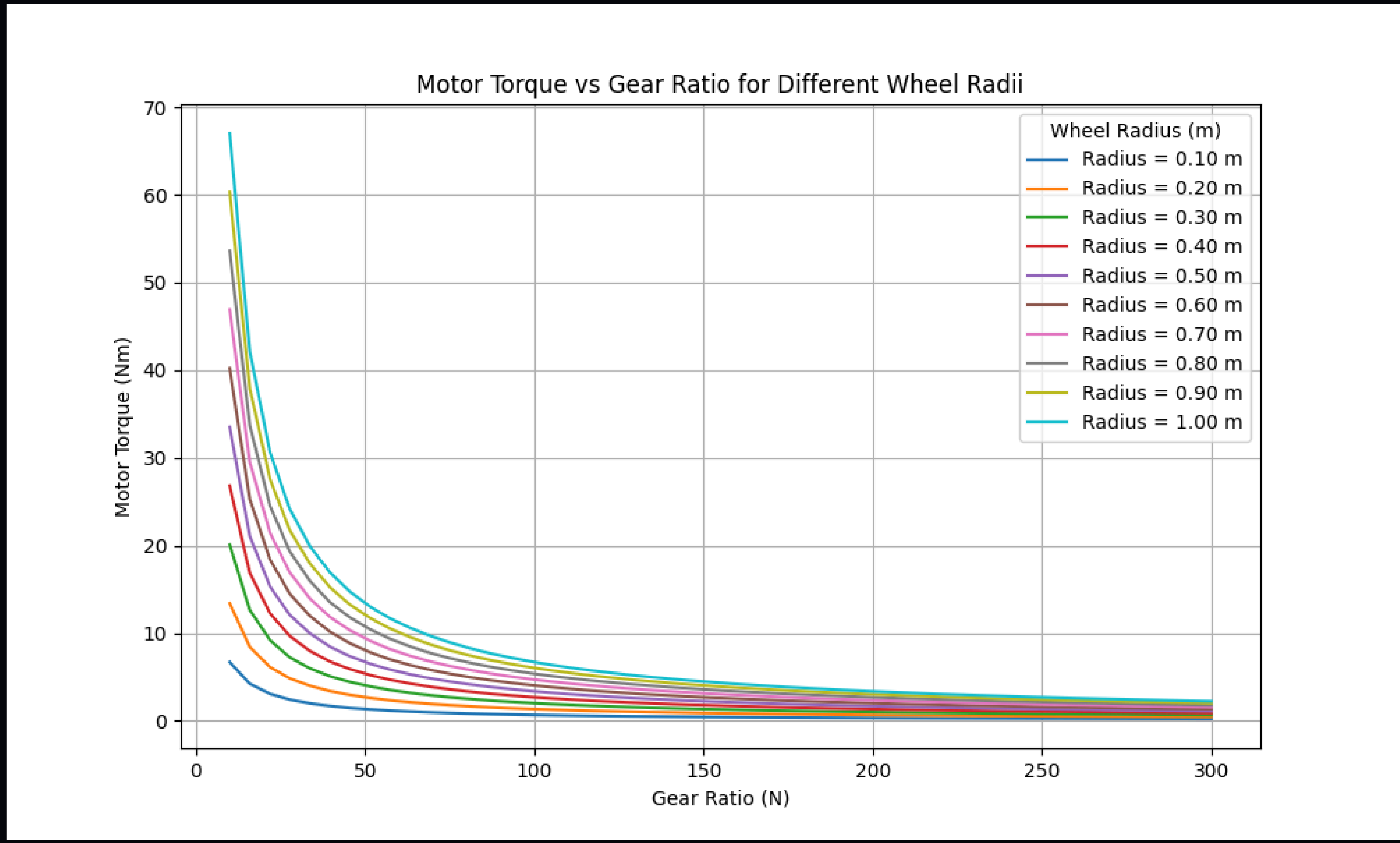
DRAWBAR PULL FOR MARS



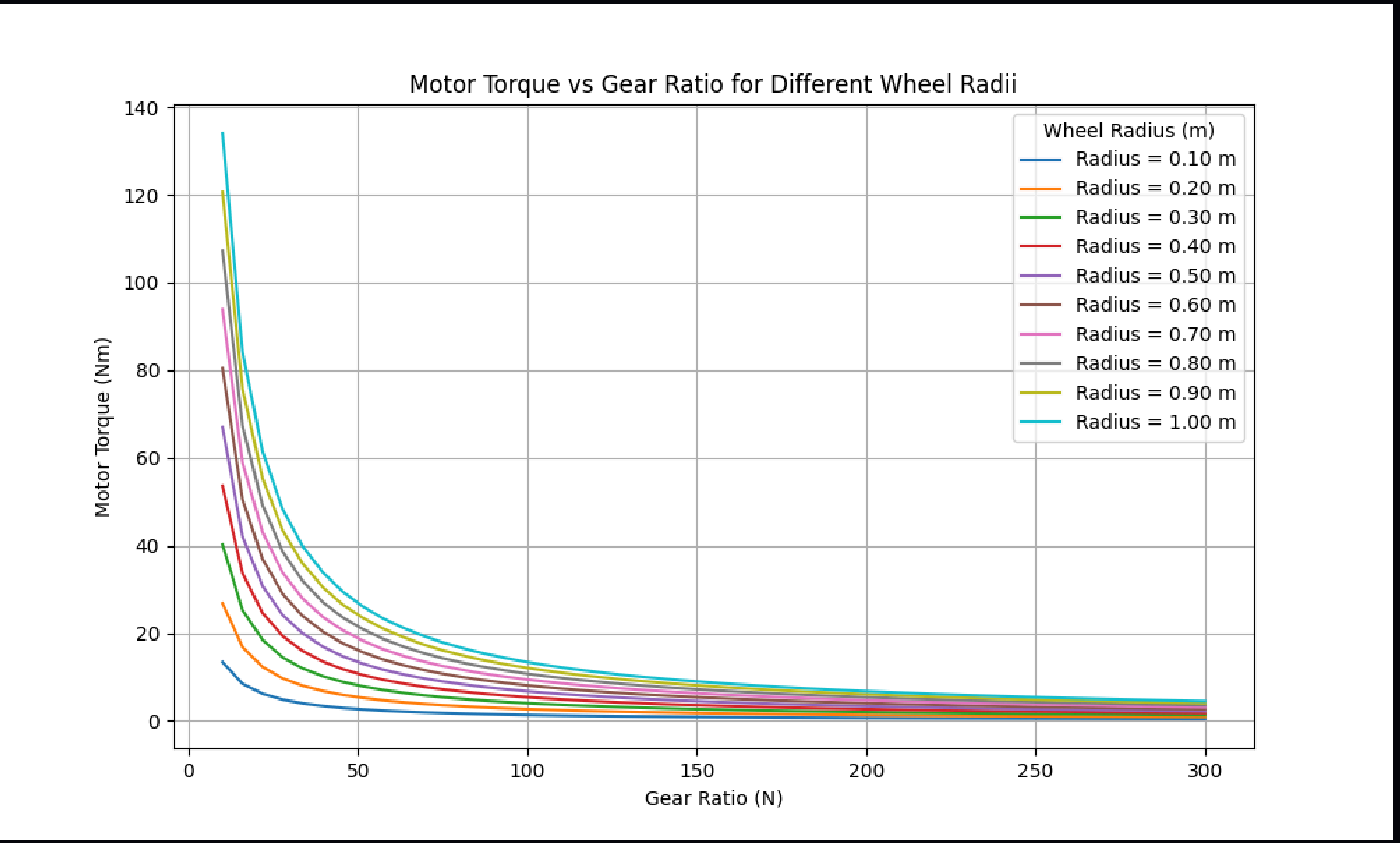
Using the same design on Mars triples both the drawbar pull and tractive force, but also doubles the total rolling resistance.

MOTOR TORQUE VS GEAR RATIO ON MARS

MOON



MARS



If we were to use the same motor on Mars, we would need to adjust the gear ratio to 150:1, resulting in the motor requiring twice the torque needed to reach a speed of 3 m/s.

REFRENCES

https://ntrs.nasa.gov/api/citations/20220010732/downloads/Terramechanics_white_paper.pdf

https://www.nasa.gov/smallsat-institute/sst-soa/structures-materials-and-mechanisms/

https://www.universal-robots.com/products/ur10e/

All the lecture notes where utilized