Lunar Rickshaw – A non-Motorized Vehicle Designed for Exploration and Rescue Missions on the Moon's South Pole

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Abstract: *We have designed a simple, lightweight vehicle concept—a Lunar Rickshaw (LR)—engineered to rapidly and safely transport an incapacitated astronaut from a remote location to the Lunar Module (LM). In addition to its primary function for emergency evacuation, the Lunar Rickshaw can also serve as a mobile platform for carrying essential tools during extravehicular activities (EVAs). Key features include a rapid fold/unfold mechanism for quick deployment and stowage, a lightweight design that ensures ease of handling even in bulky spacesuits, and robust encapsulation to prevent lunar dust from affecting moving parts. Additionally, the design incorporates redundant fixing components so that if one fails, another seamlessly assumes the load, ensuring continuous, reliable operation in the harsh lunar environment. Another key aspect of the design is its widened wheel track, which enhances safety, balance, and stability during operation. Additionally, the pulling shaft is initially stored in a folded position for compact stowage. When deployed, it is unfolded and securely locked to the frame using a Lock-and-Walk Mechanism (LWM), ensuring structural rigidity, integrity, and efficient load distribution.*

Key Words: *Moon's South Pole, Lunar Rickshaw, Emergency Evacuation, Lightweight Design, Lock-and-Walk Mechanism, Extravehicular Activities (EVAs).*

1. CONTEXT

Exploration of the Moon's South Pole has become a major focus for space agencies due to its potential water ice reserves and unique scientific value. However, this region presents extreme challenges, including permanently shadowed craters, frigid temperatures, and rugged terrain. To ensure safe and effective missions, there is a critical need for specialized vehicles capable of withstanding these harsh environmental conditions while supporting both mobility and potential rescue operations.

For this reason, upcoming lunar missions are designed as short-duration expeditions that rely on specialized vehicles to transport equipment from the Lunar Module (LM) to exploration sites—and to return astronauts safely in case of emergencies. To gather a wide

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range of innovative concepts, NASA launched a competition open to individuals and teams worldwide. Our team participated in this challenge, developing a design tailored to meet the specific requirements outlined by the organizers [1].

Our primary focus was to build upon proven designs, improving them, and innovating specific details rather than pursuing entirely radical new concepts. This approach was guided by practicality: while it is possible to envision new ideas—whether through human creativity or generative AI (see SORA [2] in action, Appendix 1)—deploying untested concepts on the Moon without extensive validation in extreme Earth environments and lunar conditions is highly impractical. Therefore our source of inspiration, among others, was the Modular Equipment Transporter (MET), which was a cart used by the Apollo 14 mission in 1971 [3].

According to the competition guidelines, the vehicle must be non-motorized, lightweight, and foldable to minimize its storage footprint. Additionally, all materials used must be capable of withstanding the extreme conditions of the Moon's South Pole. Given the harsh lunar environment, we opted not to rely on specialized diagnostic devices to monitor structural integrity—as would typically be done on Earth [4]. Instead, we focused on selecting robust, suitable materials to ensure the vehicle can reliably support a variety of mission scenarios under these demanding conditions. Furthermore, we will present a detailed description of the design, highlighting location-specific features to provide a clearer understanding of its practical application and functionality.

2. DESIGN DESCRIPTION

The LR is a lightweight and streamlined rescue vehicle, purpose-built to tackle the demanding conditions of lunar exploration. Its design focuses on simplicity and functionality, incorporating only the essential components required to meet the mission's core objectives. It is composed of four main sections: the frame assembly, the wheel assembly, the pulling shaft (PS) assembly, and the LR front support (FS) assembly (Fig. 1).

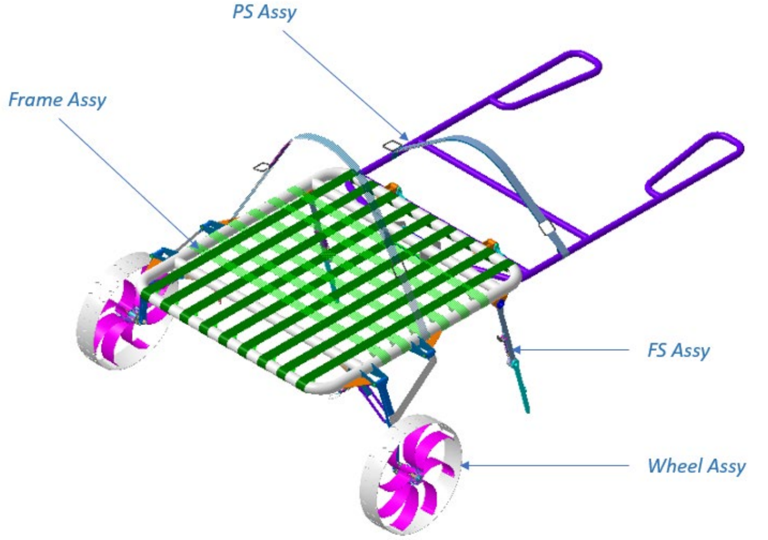

Fig. 1 – An isometric view of the LR, highlighting all its key components

<u>The frame assembly</u> is constructed from lightweight aluminum tubing and reinforced with hinge components. The assembly features a grid-like fabric for structural support and includes

a Velcro strap designed to secure either a toolbox or the astronaut in place (Fig. 2). Metal components are welded together. The grid fabric is either sewn onto the metal frame or mechanically fastened. The Velcro's hook-and-loop feature is attached to the strap through sewing or mechanical fixation. Beneath the frame, LWM is welded in place, designed to securely lock the PS during operation (refer to Appendix 2 for further details).

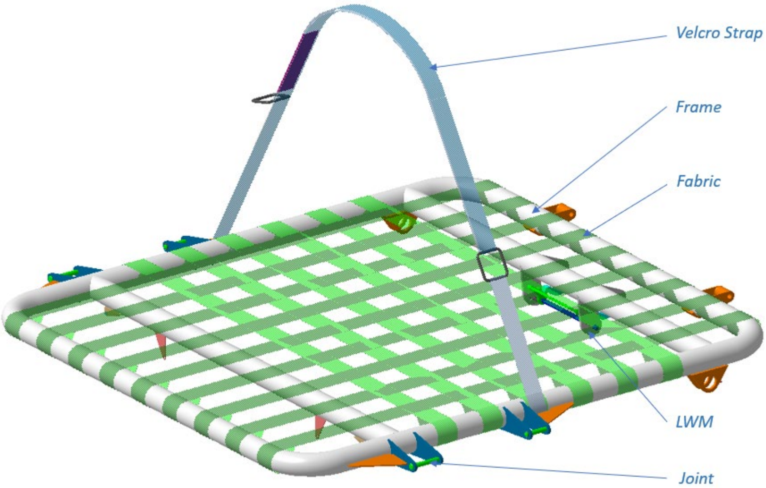

Fig. 2 – The main components of the frame assembly

The metal frame includes several holes designed to eliminate the inner tube pressure and reduce stress on the overall structure.

The wheel assembly consists of the wheel itself and the accompanying arm assembly (Fig. 3). The wheel features an outer layer made of aluminum alloy, connected to the central hub by flexible spring steel sheets that act like spokes. These are designed to absorb shocks and vibrations as the vehicle traverses the uneven lunar surface. The arm assembly comprises three main components: the main arm link, the foldable arm (FA) link, and the reinforcement (RF) link.

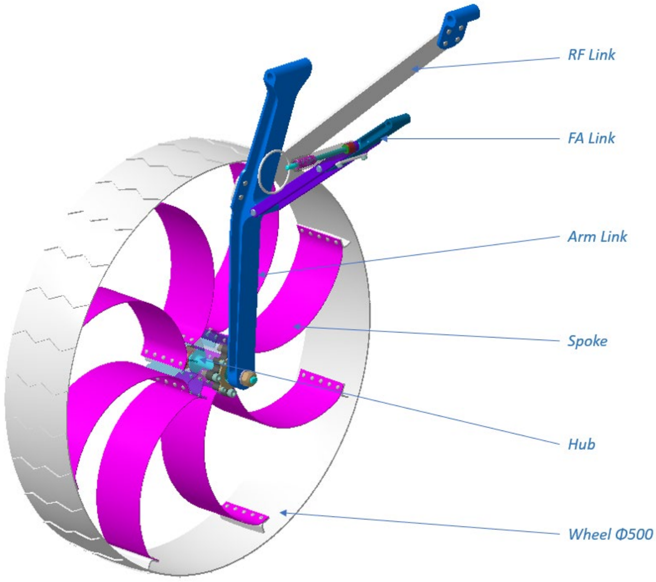

Fig. 3 – The main components of the wheel assembly

To mitigate lunar dust accumulation, the hub is equipped with a Glass Fiber Dust Sweeper (GFDS). Additionally, it features a bi-component axle designed to absorb shocks along the Y-axis. A 2 mm gap between the main and the DM axle ensures that, even in the event of a spring failure, the wheel can continue to rotate safely and reliably (Fig. 4).

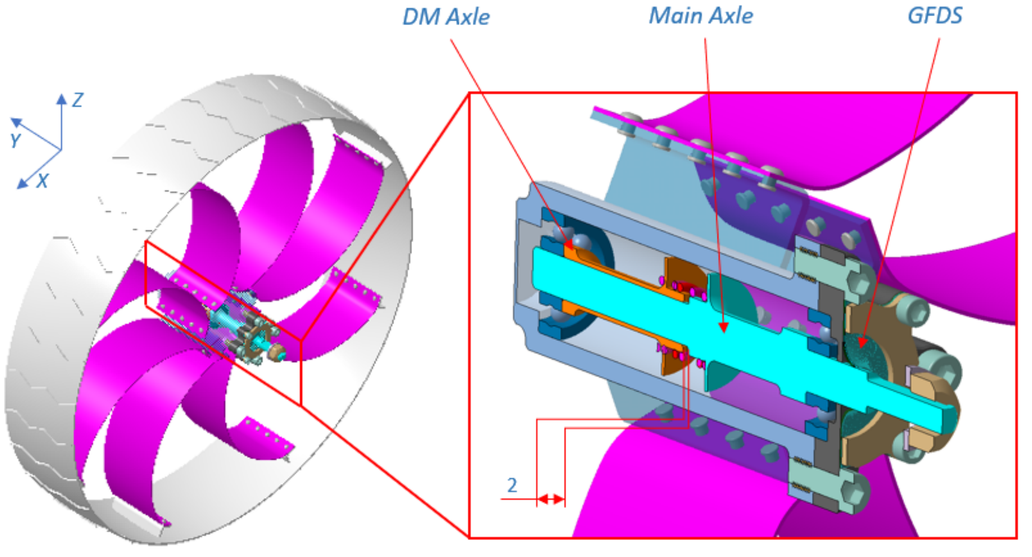

Fig. 4 – Cross-sectional view of the wheel hub, showcasing an integrated dust sweeper and a redundant Y-axis damper mechanism

To enable the folding mechanism of the wheels, we designed a foldable arm link equipped with a locking pin secured by a spring. In the event that the spring fails—due to unforeseen thermal or mechanical conditions—the astronaut can manually secure the system. This is done by inserting the pin through the Foldable Arm Link (FAL) and the Mid Foldable Arm Link (MFAL), then fastening it into the Threaded Foldable Arm Link (TFAL) (Fig. 5).

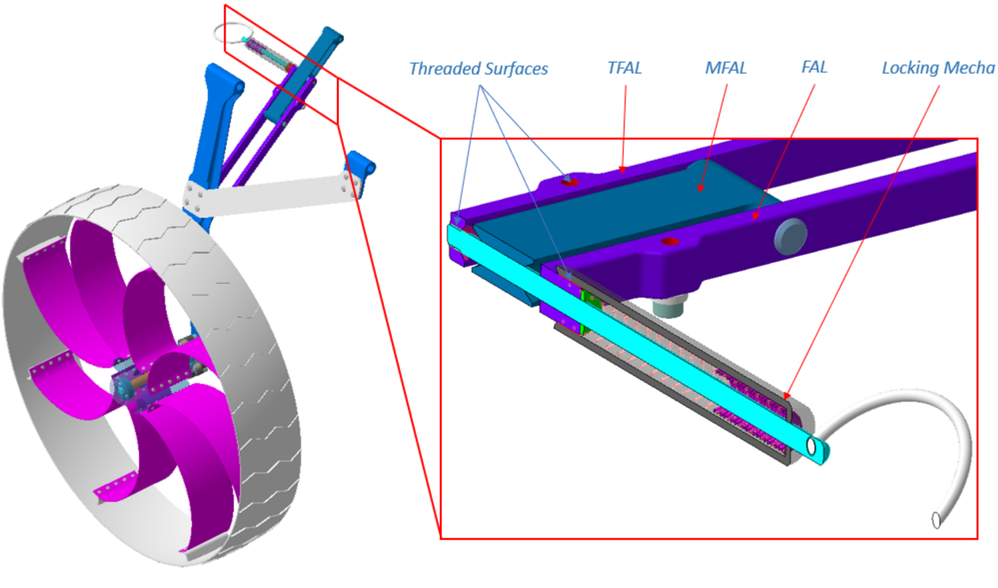

Fig. 5 – Cross-sectional view of the arm assembly's locking mechanism

The pulling shaft assembly is essentially a tubular frame designed to allow an astronaut to tow the entire vehicle. It features two hinge-like components for flexibility and includes a Velcro strap attached to the frame, intended to secure the feet of the astronaut being transported (Fig. 6). Like the main frame, it features strategically placed holes to relieve mechanical stress caused by trapped air while on Earth, which could otherwise exert pressure on the structure.

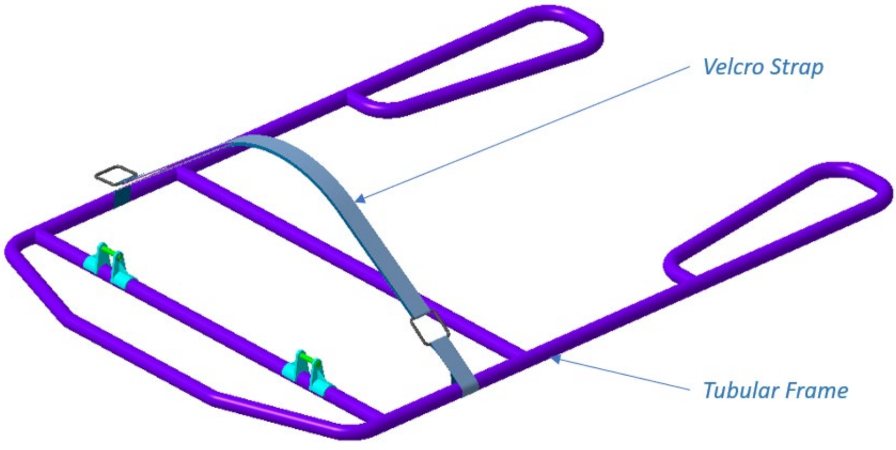

Fig. 6 – An isometric view of the PS assembly

The FS assembly consists of a free-moving joint with a defined stopping point on the main frame, an upper and lower leg, and a locking mechanism (Fig. 7). While the vehicle is in motion, both arms are allowed to rotate freely. However, when the vehicle needs to remain stationary, the upper joint engages a stopping point at the main frame's hinge, and the mid-joint is secured using a locking mechanism.

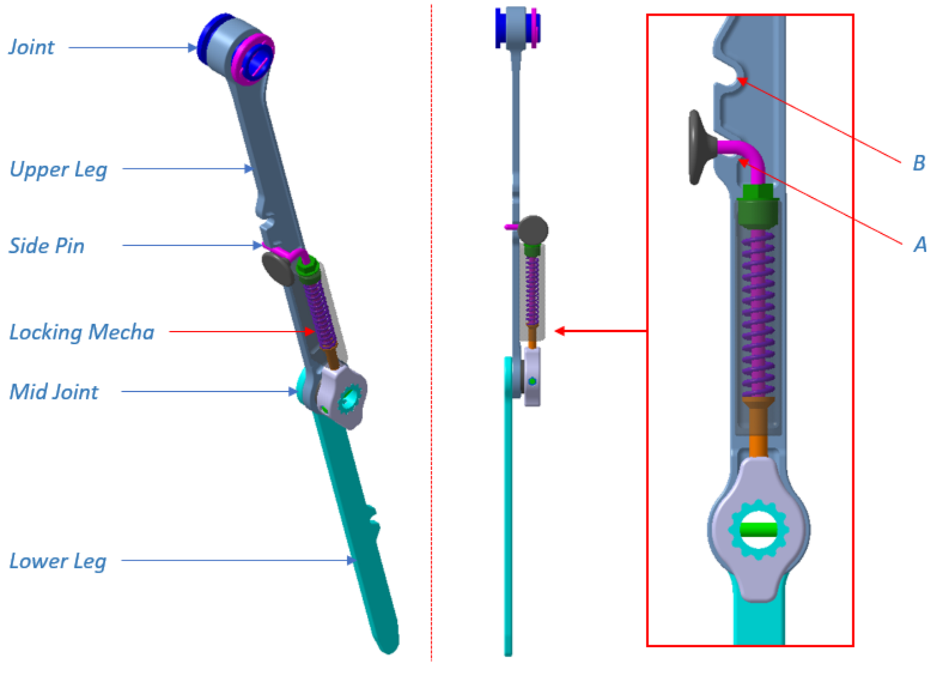

Fig. 7 – Left: FS assembly with its main components. Right: Locking mechanism detail, showing two slots — A for the locked position and B for the unlocked position.

The locking pin includes a side pin that can be positioned in one of two slots on the upper leg: position A for locked, and position B for unlocked. A key aspect of redundancy in this system lies in its safety design — the side pin can only be disengaged if the locking knob is both rotated and moved along the axis of the locking assembly, preventing accidental release.

3. MATERIALS SELECTION AND METRICS

A wide range of materials must be evaluated when designing for the unique and extreme conditions of the Lunar South Pole. For this application, we have focused on materials known for their durability and proven performance in harsh environments, making them strong candidates for lunar surface operations. Austenitic stainless steel was selected for components such as wheel spokes, springs, and bolts due to its excellent corrosion resistance and elasticity. The high melting point of stainless steel, approximately 1,420 °C, makes it a robust material for applications on the lunar surface. While gamma and cosmic radiation—both significant on the Moon—can degrade the corrosion resistance of stainless steel, this is not a major concern in the current application. The Moon's environment lacks the primary chemical agents (such as water and oxygen) responsible for corrosion on Earth, thus minimizing the risk of corrosion damage to stainless steel components.

All other metallic components in the system are fabricated from 6061 aluminium alloy, selected for its high strength-to-weight ratio, low density, and ease of machining. Although ionizing radiation may reduce aluminium's corrosion resistance, the absence of atmospheric oxygen and water on the Moon effectively eliminates typical corrosion processes. Therefore, radiation-induced degradation does not result in significant structural damage under lunar conditions. For the fabric grid and securing belts, we selected glass fiber, valued for its tensile strength and thermal stability. The Velcro components are made from polyetheretherketone (PEEK), a high-performance polymer known for its exceptional durability and chemical resistance. It is important to note that the selected materials were carefully chosen not only for their performance characteristics but also because they align with the vehicle's overall weight constraints. Included into the initial weight assessments, these materials emerged as the most advantageous selection. Given the competition's strict limitations on both weight and volume, we adopted a purposefully minimalist design approach. As a result, the vehicle's estimated total weight is approximately 21 kg (see Table 1), remaining well within the recommended limits. The total estimated volume of the LR vehicle is approximately 0.48 m³ when stowed and expands to around 1 m³ when fully deployed.

Table 1 – Weight breakdown of each subassembly within the LR vehicle

Assembly	Mass (kg)
MAIN FRAME	7.447
RH WHEEL AND ARM ASSY	3.543
LH WHEEL AND ARM ASSY	3.543
RH LEG ASSY	0.676
LH LEG ASSY	0.676
PULLING SHAFT ASSY	5.237
Total	**21.122**

4. DEPLOYMENT MECHANISM

Although this LR is designed to navigate the Moon's unique environment and terrain, its underlying operating principles remain essentially the same as those used on Earth. The design emphasizes rapid deployment, enabling astronauts to quickly unfold and activate the vehicle at the start of an Extravehicular Activity (EVA).

When stowed inside the Lunar Module (LM), the vehicle folds into a compact configuration for efficient storage alongside other mission equipment.

Once on the lunar surface, it can be fully deployed and ready for use in under five minutes (Fig. 8).

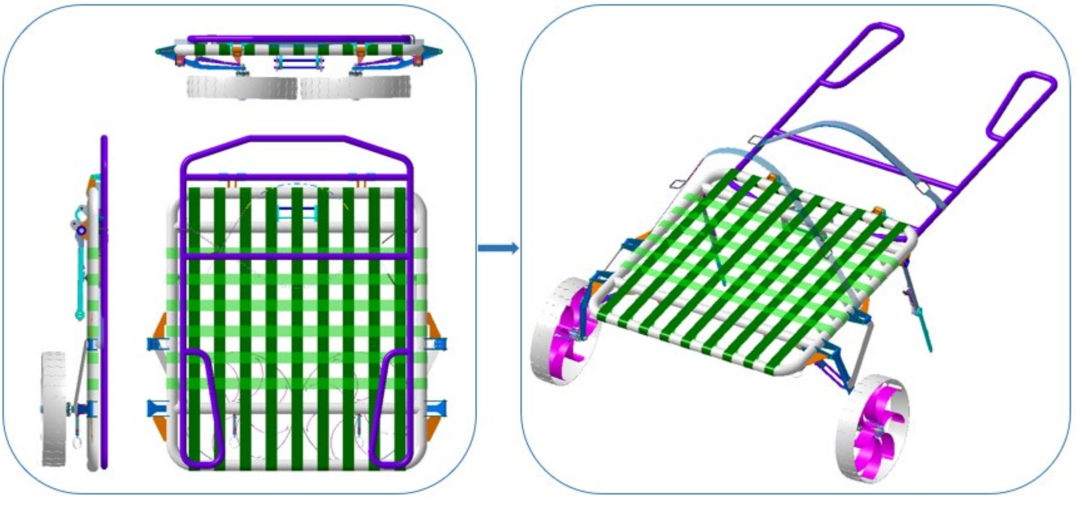

Fig. 8 – Left: Folded LR shown from top, front, and side views. Right: Unfolded LR in operational configuration.

The design was developed with ease of deployment in mind, allowing astronauts to easily perform unfolding operations even while wearing bulky space suits. To fully deploy the vehicle, a minimum of 11 steps are required (Appendix 3).

5. OPERATIONAL DETAILS

The lunar rickshaw is primarily designed to ensure the safe and efficient transportation of a fully incapacitated crew member from distances up to two kilometers back to the lunar module (LM).

Beyond this essential rescue capability, the vehicle plays a versatile and vital role in supporting EVA operations.

It primarily functions as a mobile platform, carrying critical tools and equipment required by astronauts during their explorations in the wider vicinity of the LM (Fig. 9). In emergencies, the vehicle is capable of seamlessly transitioning into an autonomous rescue mode, facilitating the swift and secure return of any compromised astronaut to safety.

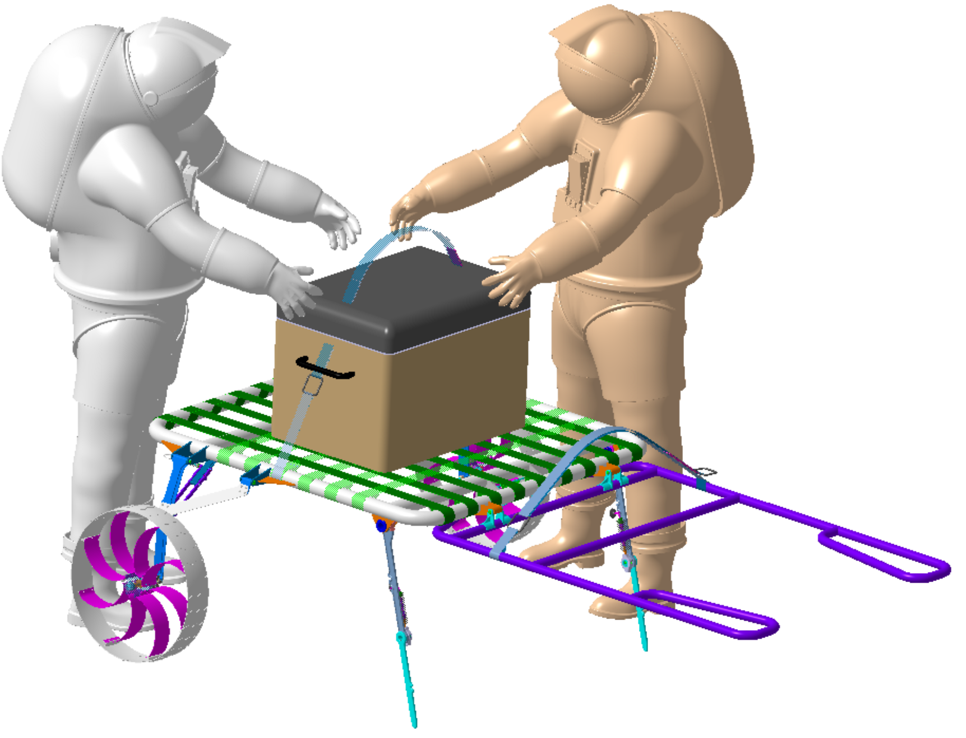

Fig. 9 – Astronauts outfitted in the Z2 Spacesuit [5] interacting with the toolbox

To assist the impaired astronaut onto the vehicle, several methods are available. If lifting them directly onto the vehicle is not feasible, an alternative approach involves tilting the vehicle to create four stable contact points on the PS and FS assemblies, allowing the astronaut to be pulled more effectively (Fig. 10).

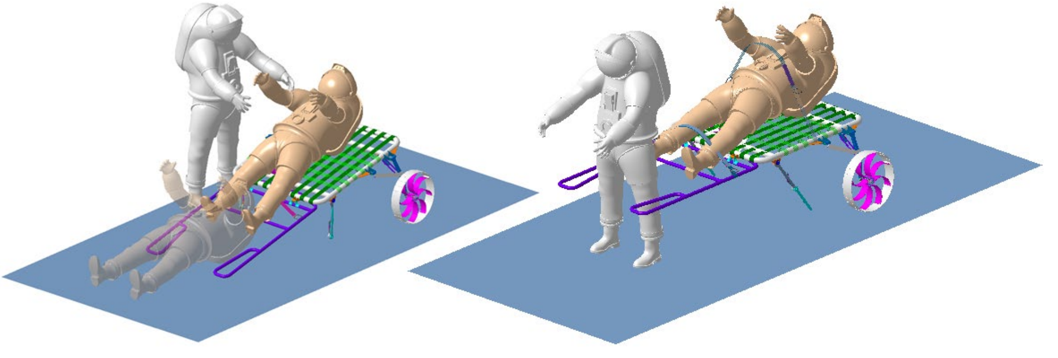

Fig. 10 – Left: An astronaut is being lifted onto a tilted vehicle by a fellow astronaut.
Right: The incapacitated astronaut is being transported using the vehicle.

The time required for one astronaut to pull a fellow astronaut back to the Lunar Module (LM) depends on several factors. These include the design of the spacesuit — which affects both the total weight and the astronaut's mobility — as well as the specific route chosen for the return, which must account for all necessary safety precautions.

For a distance of about 2 kilometers, the estimated return time ranges from 1 to 2 hours. However, this could be significantly longer if unexpected challenges arise, such as navigating terrain cluttered with rocks or craters, or dealing with a rollover incident. To prevent this, the vehicle must be designed with a track width as large as feasible. However, the track should not be narrower than the vehicle's width, nor excessively wide, as that would increase the load on the folding mechanism, as well as the vehicle's stowed volume and overall weight.

We aimed to balance all critical factors in the design of the LR, ensuring it meets safety requirements for single-astronaut towing. The vehicle incorporates sufficient redundancy to prevent sudden blockages and is engineered with enhanced stability to minimize the risk of unexpected rollovers on the Moon's rugged terrain (Appendix 4).

6. FUTURE RESEARCH

To further advance the Lunar Rickshaw (LR) design, future research should focus on several critical areas. Key priorities include:

- Comprehensive Earth-based testing under simulated lunar conditions
- Targeted design enhancements, especially of locking and securing mechanisms
- Exploration of alternative bearing solutions, such as solid-lubricated, hybrid ceramic, magnetic, or pressurized systems
- Adaptability to other planetary environments, particularly Mars
- Advanced material development and structural analysis
- Integration with broader lunar systems, including astronaut suit extensions and compatibility with future lunar robotics
- Cross-sector collaboration between space agencies, research institutions, and industry partners

Planned testing should expose the LR to Earth-based simulations of lunar surface conditions. This includes laboratory evaluations in thermal vacuum chambers using lunar regolith simulants to replicate the Moon's hard vacuum, extreme temperature fluctuations, and pervasive dust. Field tests in lunar analog environments will further validate performance.

Improved Locking Mechanisms

A primary design objective is enhancing the LR's locking systems to reliably secure payloads—such as toolboxes, scientific instruments, or injured astronauts—across rugged lunar terrain. Existing concepts like Velcro are prone to failure when contaminated with lunar dust. Thus, the next design iteration should incorporate dust-tolerant locking technologies capable of maintaining reliability in highly abrasive environments.

Advanced Material Composites for Fabric Grids and Straps

Future prototypes will explore hybrid composite materials, particularly for structural grids and load-bearing straps. Glass fiber will be combined with high-performance fibers to balance strength, durability, thermal stability, and weight efficiency. Promising combinations include:

- Glass fiber + Carbon fiber: Provides excellent impact resistance and form adaptability with minimal added weight.
- Glass fiber + Kevlar: Offers superior tensile strength and resistance to abrasion, micrometeorites, and vacuum conditions.
- Glass fiber + Basalt fiber: Delivers chemical and thermal resistance while remaining lightweight and durable.
- Glass fiber + Zylon: Enables high flexibility and strength under thermal and chemical stress.
- Glass fiber + CNT yarns: Maximizes tensile strength, thermal resilience, and radiation resistance.

Material Candidates for Other Structural Components

To endure the Moon's extreme environment, high-performance materials will be considered for various structural parts:

- Inconel – Excellent high-temperature strength and corrosion resistance
- Titanium alloys – High strength-to-weight ratio and durability
- 5083 Aluminum – Exceptional corrosion resistance
- Nomex – Flame resistance and thermal stability
- Kapton – Ideal for high-temperature and electrical insulation
- Dyneema-Titanium Composite – Exceptional strength with minimal weight

Structural and Thermal Analysis

Understanding material behavior under lunar conditions is essential. Future research will include simulations and testing to evaluate:

- Material stress-strain characteristics between -200°C and +50°C
- Effects of rapid thermal shock across this temperature range
- Internal stress propagation under both loaded and unloaded conditions
- Material limits and failure thresholds in lunar-like environments

These analyses will include, but are not limited to, the following:

- Static mechanical and thermal stress analysis
- Modal (vibration mode) analysis
- Random vibration response
- Shock response to thermal and mechanical stimuli
- Material degradation and corrosion studies
- Fail-safe and redundancy assessments
- Mechanical testing of non-metallic materials

Optimized Composite Structures for Mass Efficiency

To reduce mass—especially in elements like pipes and enclosures—future designs may incorporate composite materials with optimized, hollow-wall geometries (e.g., cylindrical, prismatic, or Schwarz minimal surfaces). Candidates include graphite-epoxy and aramid-epoxy composites for their low weight, high strength, and thermal stability. For radiation shielding, thin lead layers can be embedded within composite matrices. Alternating these with structural materials can offer localized protection without excessive weight. Vacuum compatibility is critical; all materials must meet the ASTM E595 standard for outgassing, ensuring total mass loss and collected volatile condensable materials do not exceed 1.0% [6].

Radiation Resistance and Material Longevity

Materials like PEEK, though radiation-resistant, may degrade under long-term exposure to gamma rays and cosmic radiation, leading to chain scission and crosslinking damage. To mitigate this, thin lead wire networks could be integrated into the structure to absorb radiation. However, this must be optimized to minimize added mass while maintaining protection. The continued development of the LR will require a multidisciplinary and collaborative approach. By refining its mechanical systems, validating performance under lunar-like conditions, integrating advanced materials, and ensuring compatibility with broader mission architecture, the LR can evolve into a dependable, multifunctional asset. Its potential applications—from logistics and emergency transport to scientific support—position it as a crucial tool for the next generation of lunar exploration and, eventually, interplanetary missions.

ACKNOWLEDGEMENTS

As previously mentioned, this design was originally proposed for the "South Pole Safety: Designing the NASA Lunar Rescue System" competition. Although it was not selected by NASA, we believe it holds significant potential and could still serve as a valuable backup solution for other space agencies, should alternative designs be chosen as primary options.

We would like to express our sincere gratitude to the organizers for the opportunity to participate in such an engaging and thought-provoking challenge.

We would also like to extend our thanks to Tommy Mueller for sharing his model of the Z2 Extravehicular Mobility Unit (EMU) on GrabCAD [5]. His detailed suit provided a valuable dimensional reference that greatly supported the development of our vehicle design.

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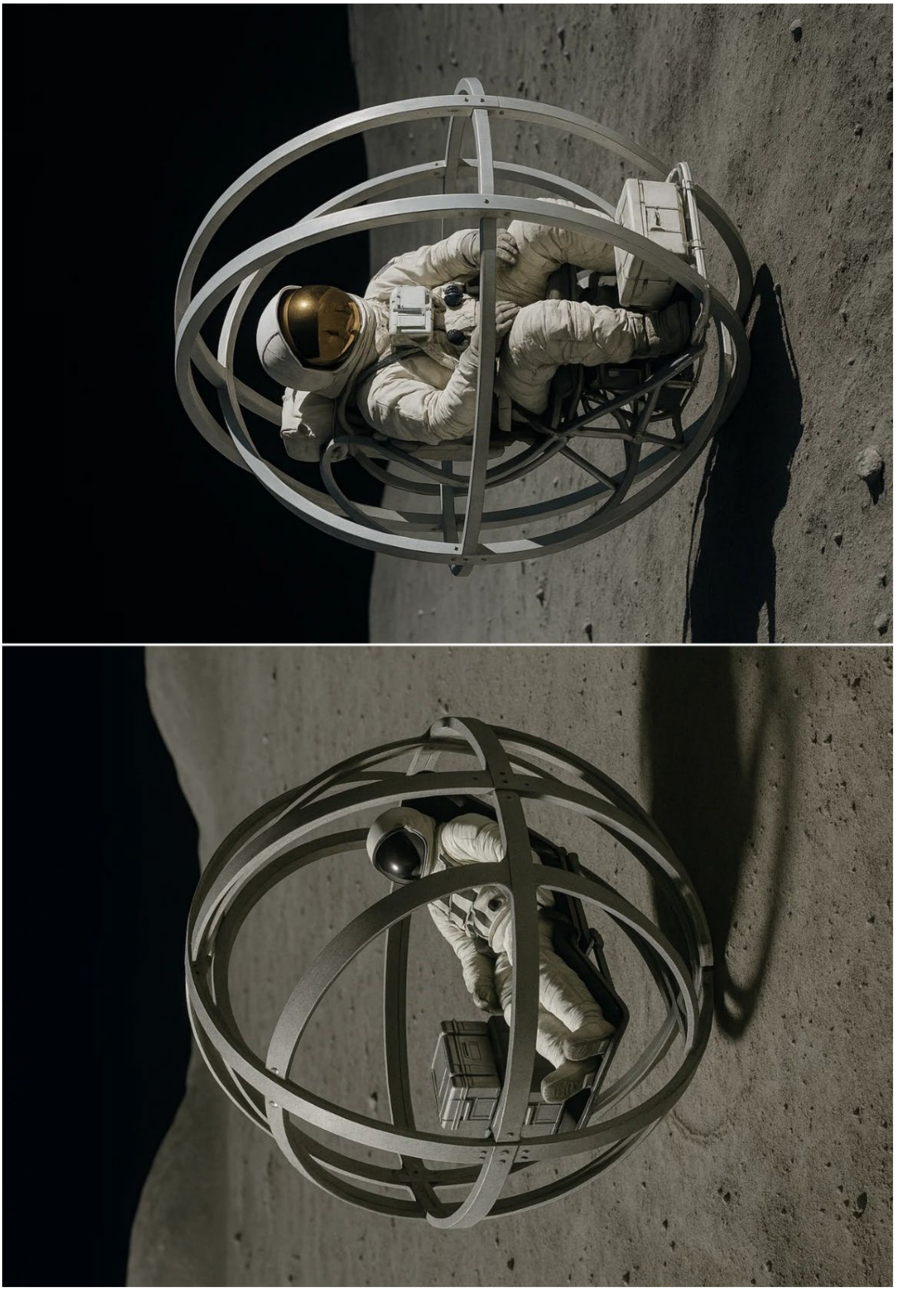
Appendix 1 – SORA generating a gyroscopic, sphere-like vehicle designed for use on the lunar surface, capable of transporting both equipment and astronauts across challenging terrain



Appendix 2 - LWM – Locking Mechanism for PS

The pulling shaft (PS) is designed to freely rotate around the main frame, allowing the LR to be stowed in a very compact configuration.

However, during operational mode, the PS must be rigidly secured to the main frame. This requirement arises because the LR is equipped with only two wheels, making stability dependent on a fixed PS.

To address this, we developed a highly efficient Lock-and-Walk Mechanism (LWM), which enables rapid and secure fixation of the PS to the main frame (see Fig. 1).

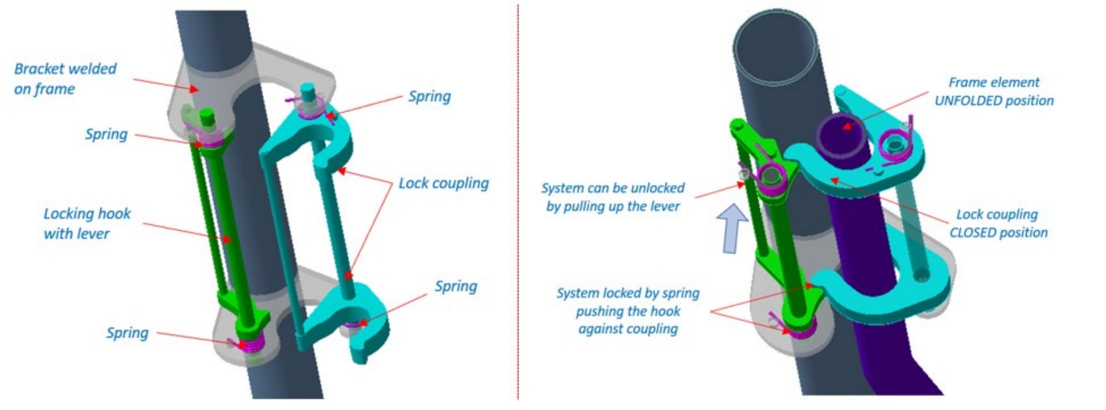


Fig. 1 – Left: LWM in the open position. Right: LWM in the closed position.

The astronaut can secure the PS simply by rotating it, causing the lock coupling to engage and activate the locking hook, with both components ultimately reaching their final locked position (Fig. 2).

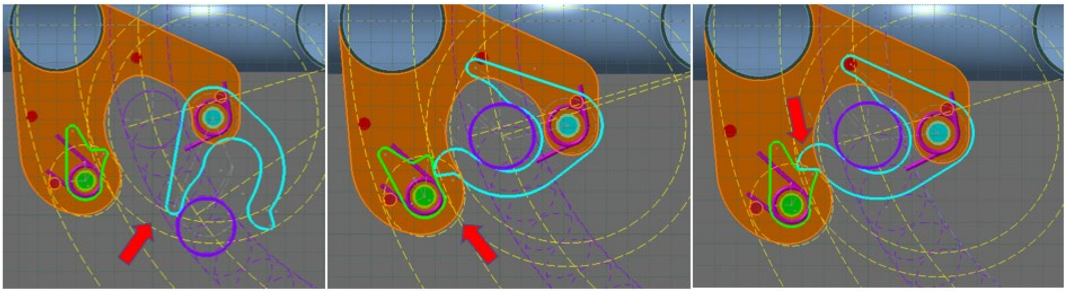
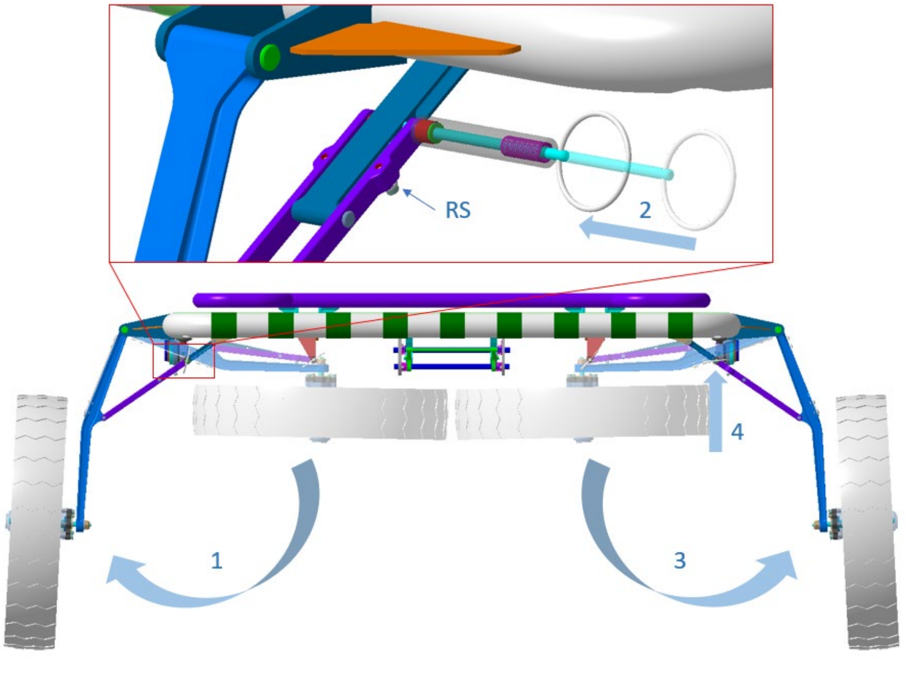


Fig. 2 – Left: Unlocked position – the PS frame pushes the lock coupling.
Center: Intermediate position – the lock coupling engages and pushes the locking hook.
Right: Locked position – the locking hook secures itself by pressing against the lock coupling.

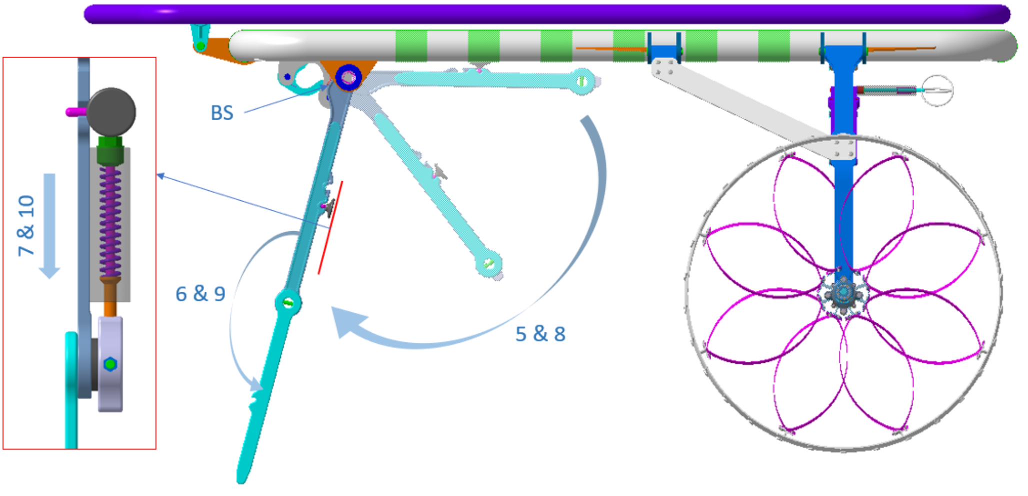
As a redundancy measure, a solution similar to those used in previously presented locking systems could be implemented. However, this aspect will be addressed in a future study.

Appendix 3 – Step-by-Step Guide for Unfolding the LR

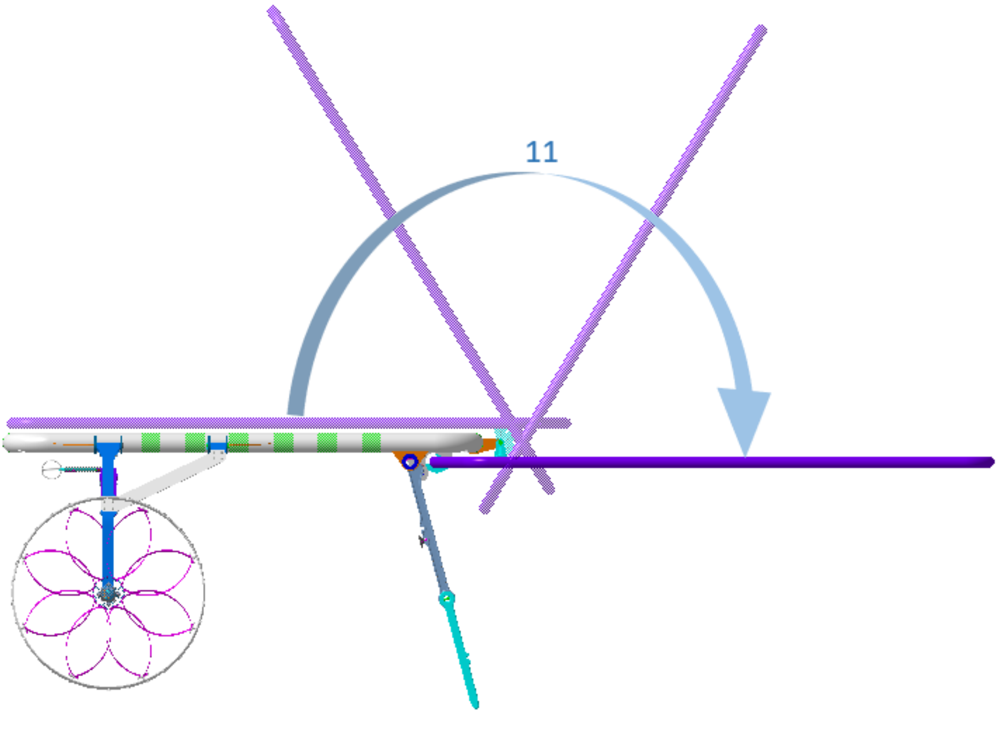
	Description
STEP 1	Rotate LH Wheel until MFAL aligns and rests against the RS
STEP 2	Lock LH Wheel
STEP 3	Rotate RH Wheel until MFAL aligns and rests against the RS
STEP 4	Lock RH Wheel
STEP 5	Rotate Folded LH FS until it aligns and rests against the BS
STEP 6	Rotate LH Lower Leg until it aligns with the Upper Leg
STEP 7	Lock LH FS
STEP 8	Rotate Folded RH FS until it aligns and rests against the BS
STEP 9	Rotate RH Lower Leg until it aligns with the Upper Leg
STEP 10	Lock RH FS
STEP 11	Rotate PS until its blocked by the LWM



Steps 1 - 4



Steps 5 - 10



Step 11

Appendix 4 – Rollover Risk Evaluation Across Neighboring Crater Rims

Irregular or unstable surfaces can introduce unpredictable changes in speed or direction, potentially exceeding the astronaut's ability to respond effectively. That's why, regardless of its simplicity, the vehicle must be designed to respond effectively in typical situations like this.

The risk of rollover or slippage near and around craters must be carefully assessed by the pulling astronaut. To maintain control, the astronaut must continuously adjust the trajectory, speed, and applied force on the pulling shaft.

However, in certain scenarios (such as the one illustrated in Fig. 1), the risk of rollover rises significantly with increasing terrain complexity, such as dunes, rocks, and other irregular features observed on the rim and the ejecta blanket.

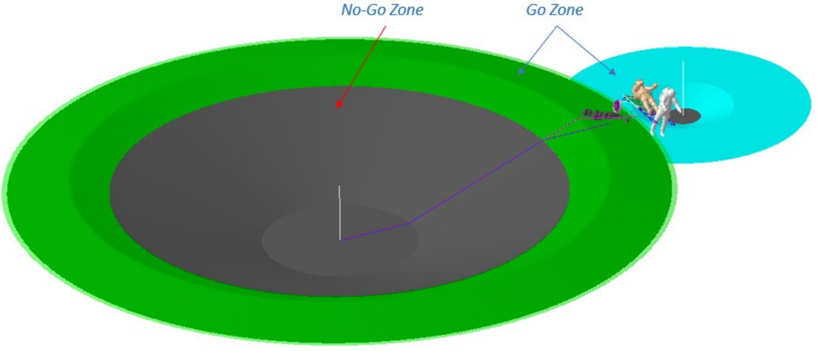


Fig. 1 – Left: A crater with walkable terrain only on the surrounding ejecta, highlighted in green.
Right: A rimless crater featuring walkable areas both around it and along its inner wall, in blue-green.

The astronaut may choose to navigate around the crater by traversing the ejecta blanket along its outer edge. This surface may include dune-like formations, scattered rocks, or a combination of both. Additionally, rimless secondary craters could be present within or near the ejecta zone. We have considered that such terrain features—whether rocks, dunes, or both - may introduce elevation changes of 150 mm or more. In this scenario, we will perform a straightforward evaluation of how the vehicle's tilt and the effects of centrifugal force influence the stability of the LR. Specifically, we aim to determine whether the astronaut, while exerting a pulling force, must apply additional effort to prevent the LR from tipping over. If so, we need to determine whether an additional force—beyond gravity—is required to act on or near the center of gravity (CG).

To perform this analysis, it is important to estimate the radius of the LR's trajectory around the crater, as well as the potential range of velocities it may experience (Fig. 2).

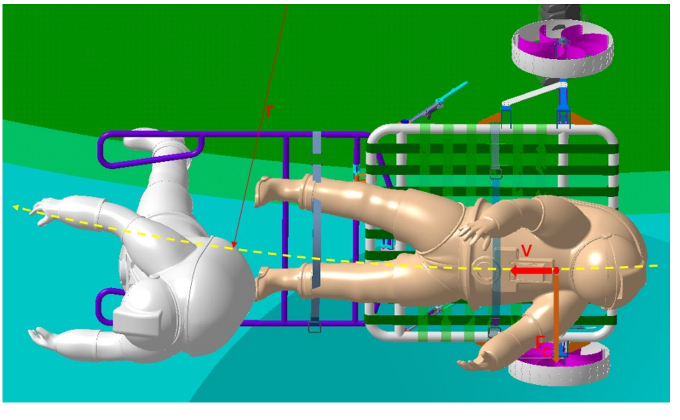


Fig. 2 – Top-down view of a vehicle moving along a circular trajectory at a constant speed v

For simplicity, we assume that the center of mass (CM) and the CG are identical. Additionally, we consider that the forces acting on the CM, the flipping point (FP), and the additional force all lie within the same plane (Fig. 3). Similarly, we consider the velocity to be constant, despite its actual variability with the terrain. A more comprehensive analysis accounting for these and other variations should be pursued in future works.

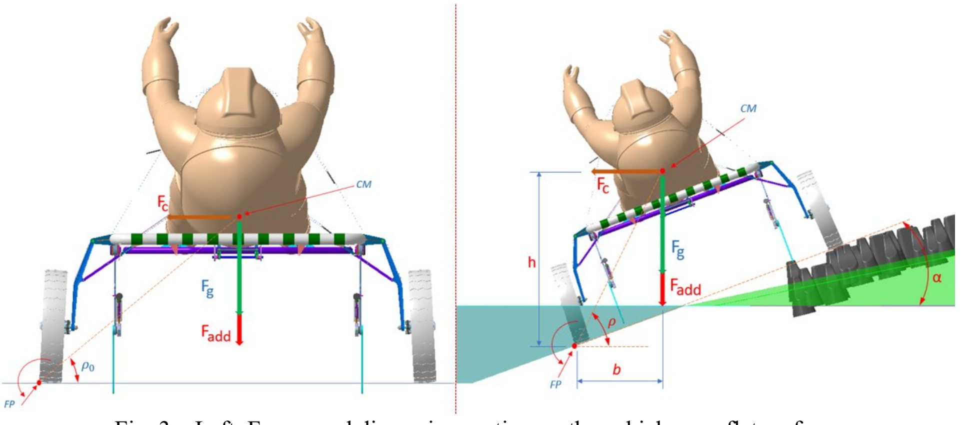


Fig. 3 – Left: Forces and dimensions acting on the vehicle on a flat surface.
Right: Forces and dimensions acting on the vehicle inclined at an angle α.

To prevent the car from flipping over, we need to determine whether an additional downward force is necessary to counteract the torque generated by the centrifugal force. This involves calculating the torque produced by the centrifugal force and comparing it with the combined torque from gravity and any additional force.

To proceed with these calculations, we need to make certain assumptions – see Table 1.

Table 1 – All relevant parameters contributing to the evaluation of the additional force.

Parameters	**Description**
m	Mass of the LR and the astronaut with or without tools
g_{moon}	Gravitational acceleration on the Moon
r	Radius of the circular trajectory
v	Tangential velocity along a specified path
h	Vertical lever arm of the centrifugal force during lateral tilting
b	Vertical lever arm of the gravitational force during lateral tilting
α	Tilting angle
ρ_0	The angular deviation of the CM–FP line relative to the horizontal plane wile the vehicle is level
ρ	The angular deviation of the CM–FP line from the horizontal plane due to vehicle tilt
F_g	Gravitational force
F_c	Centrifugal force
F_{add}	Additional force
τ_c	Torque due to centrifugal force
τ_g	Torque due to gravity and additional force

Torque due to Centrifugal Force (τ_c)

$$\tau_c = F_c \cdot h \tag{1}$$

$$F_c = \frac{m \cdot v^2}{r} \tag{2}$$

$$\tau_c = \frac{m \cdot v^2}{r} \cdot h \tag{3}$$

Torque due to Gravitational and Additional Force (τ_g)

$$\tau_g = (F_g + F_{add}) \cdot b \tag{4}$$

$$F_g = m \cdot g_{moon} \tag{5}$$

Condition for no-flipping:

To prevent flipping, the gravitational torque must be equal to or exceed the centrifugal torque.

$$\tau_g \geq \tau_c \tag{6}$$

Insert (3), (4), (5) in (6)*:*

$$(F_{add} + m \cdot g_{moon}) \cdot b \geq \frac{m \cdot v^2}{r} \cdot h \tag{7}$$

Rearrange for F_{add}:

$$F_{add} \geq m \cdot (\frac{v^2}{r} \cdot \frac{h}{b} - g_{moon}) \tag{8}$$

Lever arms:

$$\rho = \rho_0 + \alpha \tag{9}$$

$$\frac{h}{b} = \mathrm{tg}(\rho_0 + \alpha) \tag{10}$$

Insert (10) in (8)*:*

$$F_{add} \geq m \cdot [\frac{v^2}{r} \cdot \mathrm{tg}(\rho_0 + \alpha) - g_{moon}] \tag{11}$$

The gravitational acceleration on the Moon, g_{moon}, is approximately *1.62 m/s²*. The combined mass of the vehicle, astronaut, and additional equipment is estimated to be around *400 kg*.

The reference angle ρ_0 for our LR is approximately 46°. All other parameters will be explored across a range of values to capture a broad spectrum of possible scenarios and operating conditions (Fig. 4).

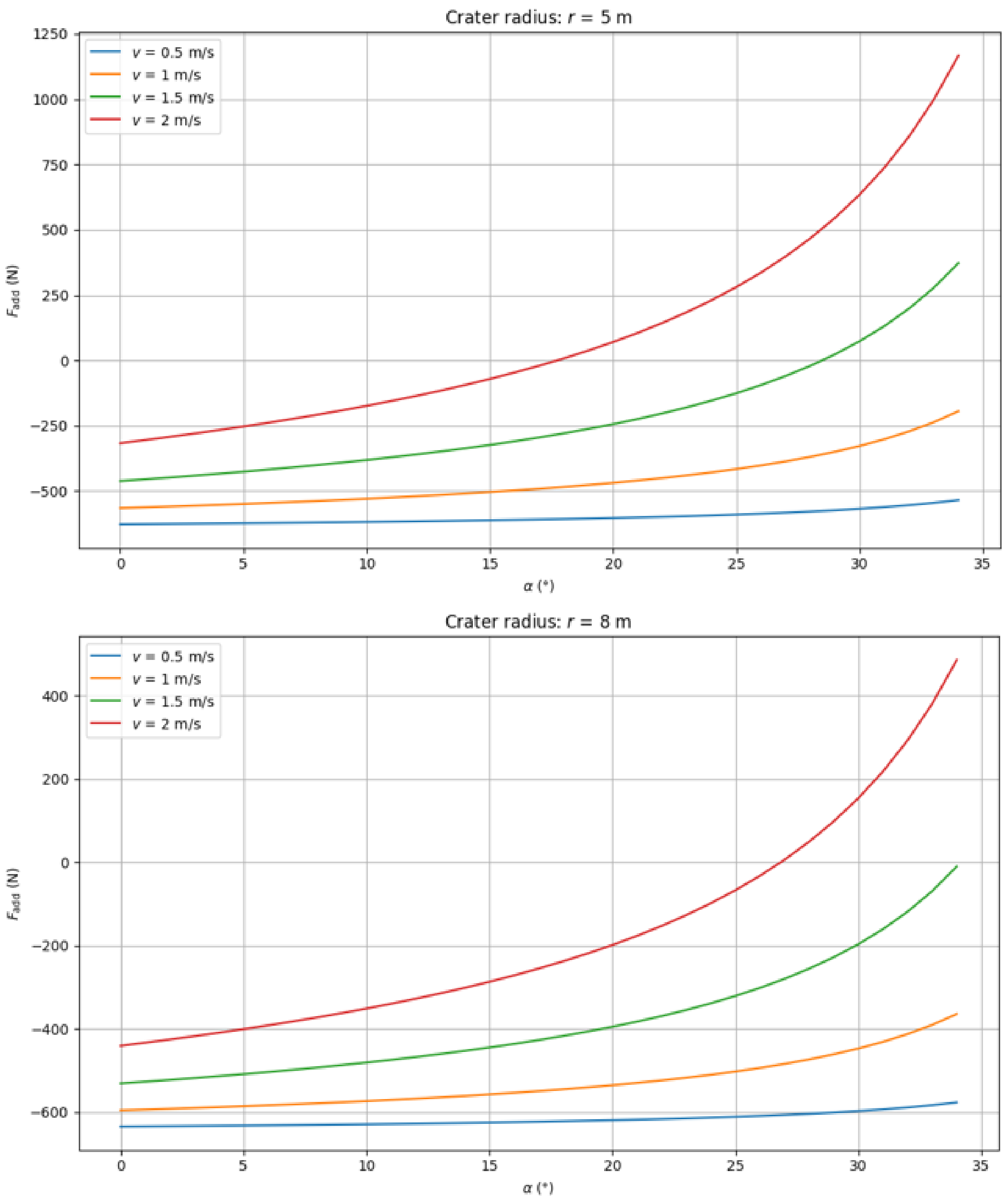


Fig. 4 – Graphs illustrating how the additional force varies
with tilting angle across different vehicle velocities and crater radii.

The above graphics indicate that the vehicle should not tilt more than 30°, and the astronaut's speed should remain below 1.5 m/s to prevent the need for additional counteracting force against centrifugal effects.

Given the limitations of the astronaut suit, it's clear that such speeds won't be reached. However, the astronaut should exercise caution on inclined terrain, where local speeds may increase. Nevertheless, our vehicle is capable of responding appropriately to these variations.

In comparison, selecting a similar vehicle with its wheels positioned almost beneath the main frame - corresponding to a reference angle ρ_0 of approximately *55°*—will, in most cases, require the astronaut to apply additional forces. This significantly increases the risk of the vehicle tipping over, particularly as the tilt angle becomes more pronounced (Fig 5).

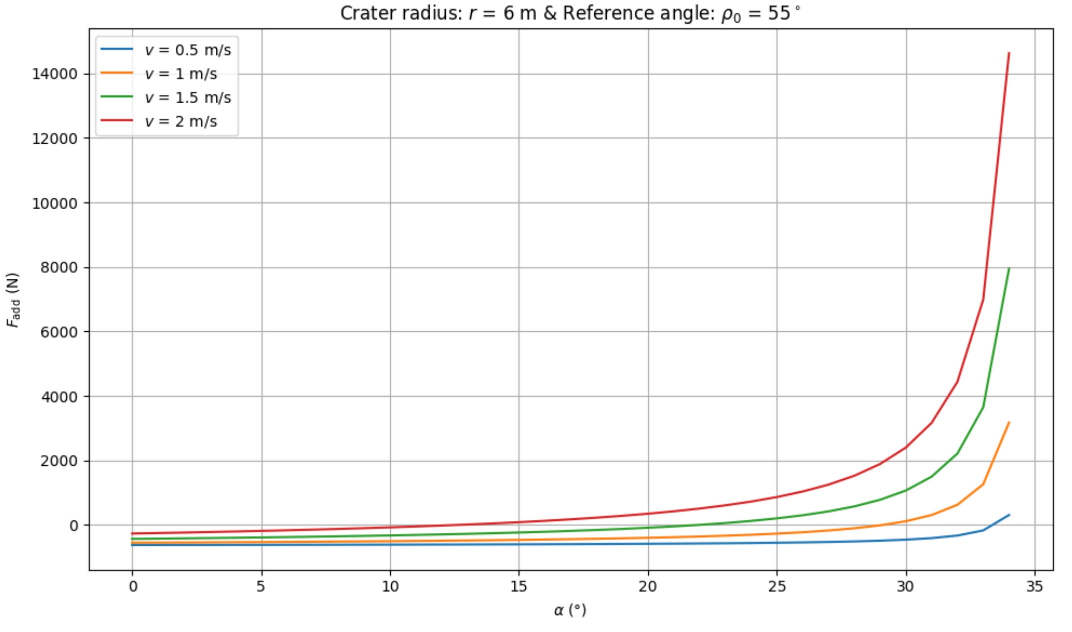


Fig. 5 – The graph illustrates significantly higher additional forces at steeper tilt angles, particularly for vehicles with a narrow track width

In conclusion, our design effectively addresses this safety issue while remaining compliant with the competition's requirements, particularly regarding mass and volume constraints.