



Lunar Environment and Terrain Considerations for Hardware Design

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Lunar Regolith

- **Gardening-**
The mixing and fragmentation process on the lunar surface due to meteor impacts
- Gardening creates....
 - highly irregularly shaped particles that are unlike anything on Earth
 - Lunar breccias
 - **Agglutinates**
- Primarily silicates and metallic oxides
- Mean grain size $\sim 70 \mu\text{m}$
- Regolith may be comprised of about 60% agglutinates by volume

Images from <https://curator.jsc.nasa.gov/lunar/samplecatalog/>



Apollo 15 rock sample (mm scale).



Apollo 17 sample (mm scale).



Apollo 12 sample (cm scale).

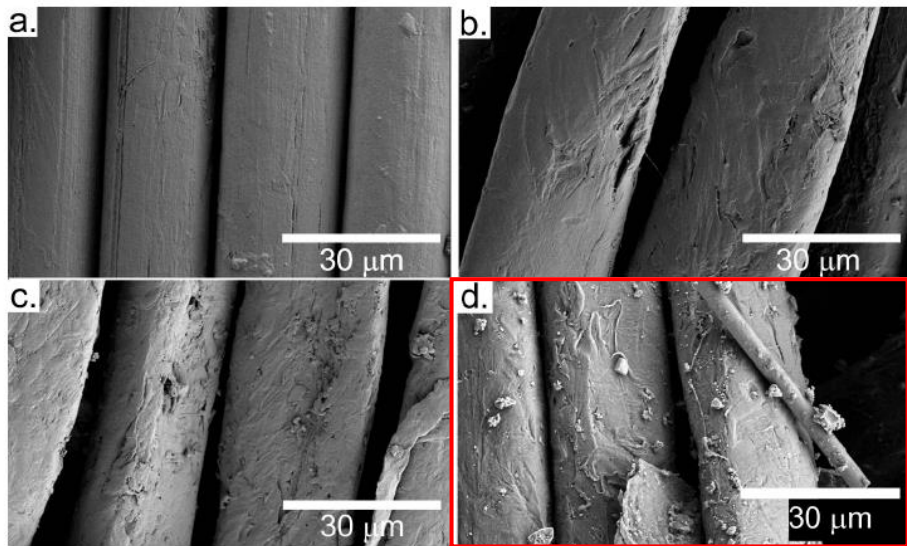


Figure 11. Secondary electron SEM images showing progressive fabric wear and damage of T-164 Teflon[®] fabric from Apollo 12 ITMG. (a) Unused Apollo-era T-164 Teflon[®] fabric. (b) Unexposed T-164 Teflon[®] fabric from under flag patch. (c) Exposed shoulder area next to flag patch. (d) Left knee area with particulates and glass fiber.

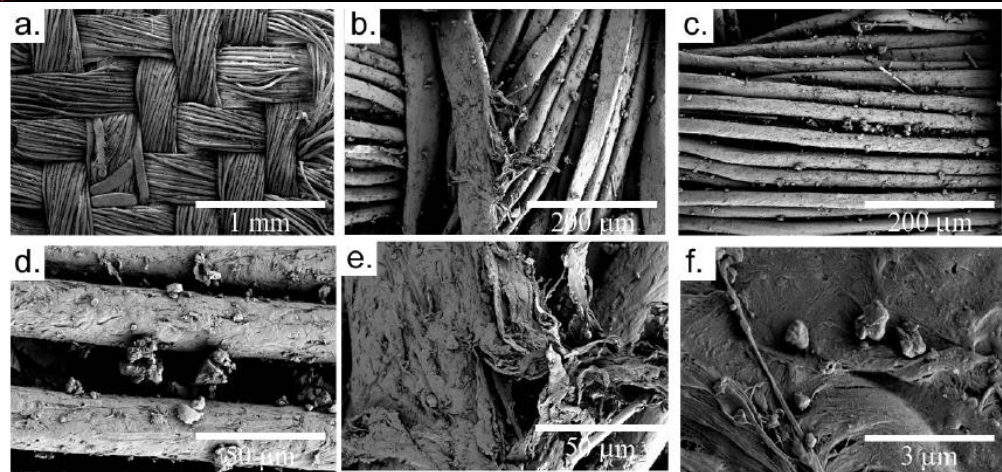


Figure 7. SEM secondary electron images of T-164 Teflon[®] from left knee area of Apollo 12 LMP ITMG.



Figure 5. ITMG from model A7L spacesuit worn on the lunar surface by Apollo 12 LMP Alan Bean. Image originally appeared in NASA TR-169-001, prepared at the WSTF.

Lunar Dust Abrasion Apollo 12 Spacesuit

- EVA Duration: **7 hr. 45 min.**
 - [EVA 1: 3 hr. 55 min., EVA 2: 3 hr. 50 min.]
- Landing Site: Oceanus Procellarum
— Ocean of Storms
 - (3.01S, 23.42W) (site 7)

Images from <https://ntrs.nasa.gov/citations/20090015239>

Lunar Gravity: Reaction Forces and Design

Caterpillar 6015 Hydraulic Mining Shovel

On Earth

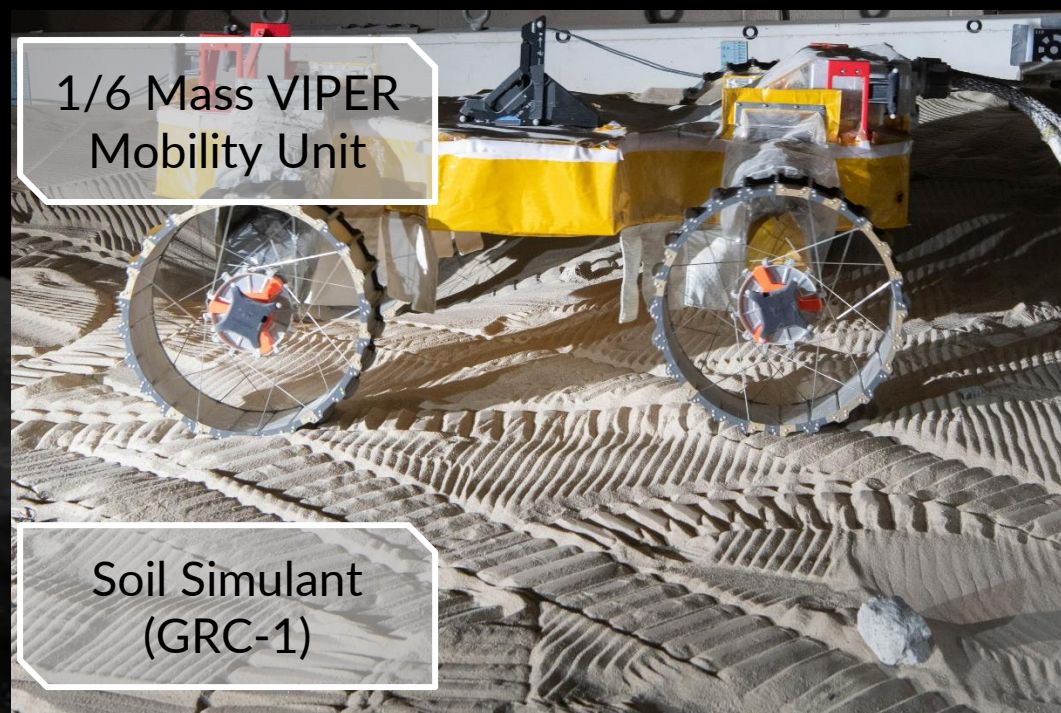
- Weight: 660 ton $\rightarrow$ 1,320,000 lbf
- Vehicle Mass: 598,742 kg
- Estimated Max Drawbar Pull: 660,000 lbf
 - Rule of thumb $\sim\sim$ 50% of vehicle weight

On the Moon

- Weight: $(1,320,000 \text{ lbf})/6 = 220,000 \text{ lbf}$
- Vehicle Mass: 598,742 kg
- Estimated Max Drawbar Pull: 110,000 lbf



Lunar Gravity: Reaction Forces Test Considerations



- Gravity offload or $1/6$ vehicle mass **only accounts for half of the gravity problem**
- Driving medium still under $1g$ gravity environment
 - Inter-particulate interactions heavily influenced by gravity
- GRC-1 designed to have comparable cone penetrometer gradients from Apollo missions in $1g$

Lunar Regolith Simulants

- **No perfect simulant to replicate lunar soil**
 - **Even lunar soil isn't always useful on Earth due to gravity and atmospheric differences**
- What characteristics do you care about for your test?
- What can you financially afford for your test?
 - Limiting factor, many are very expensive
- How much simulant do you need for your test?
 - Limiting factor, not all are available in large quantities
 - Not all are reusable for certain tests
- What level of fidelity for a characteristic do you need for your test?
 - Cost goes up with fidelity

Simulant Characteristic
Chemistry/Composition/Minerology
Particle Size Distribution
Max/Min particle size (pebbles/rocks?; fines/dust?)
Particle Shape
Magnetic properties
Optical properties/dielectric
Porosity/Permeability
Abrasion properties (hardness, glass content)
Electrostatic properties
Thermal properties (e.g., conductivity)
Geotechnical properties (bearing capacity, angle of repose, shear strength, etc.)