NASA Lunar Grounding Challenge: Description of the Concept

DragonWorx GroundSkin

A passive, charge-managed outer layer with a distal-resistor discharge wand. Submitted by Evan Norman, Founder, DragonWorx Biomimetic Technologies, Richardson, Texas (getdragons@dragonworx.bio).

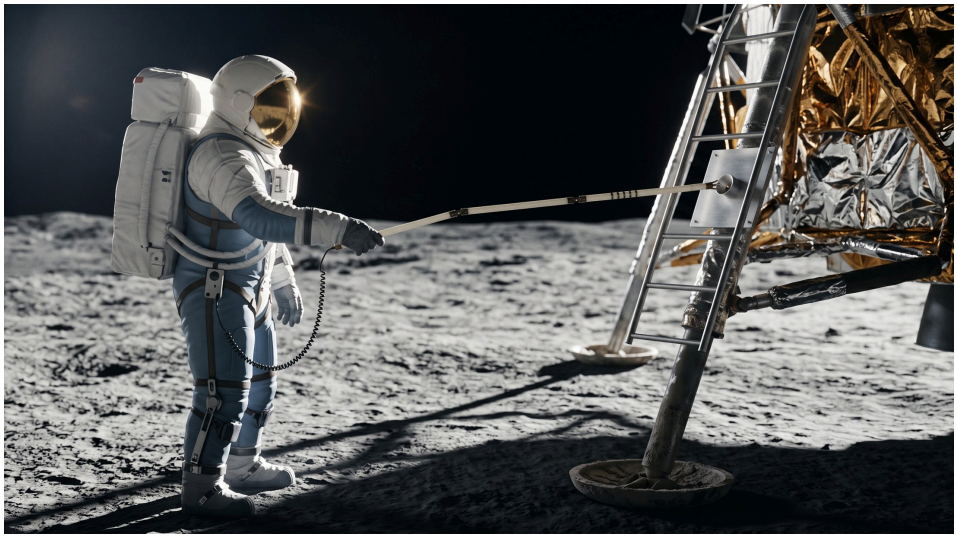


Figure 1. Lander return. The astronaut stops about a metre from the lander and seats the wand tip in the target before anything else touches the lander.

1. Summary

GroundSkin brings a suited astronaut at −100 kV to the potential of a +100 V lander through one defined, current-limited path, and keeps every arc off the suit. It has three parts. A **Discharge Wand** carries a 1.00 GΩ chain of four high-voltage resistors at its far end, so the whole voltage drop sits more than 0.68 m from the glove. A **GroundSkin** layer, a dissipative coating on the outer panels the astronaut already wears, ties those panels and the suit's bonding point into one node through resistive bleed tabs. A **Lander Discharge Target**, a bare aluminium plate with a capture cone, bolts to the lander's bonding point. Nothing in the system draws power, and nothing alters the suit material.

Challenge threshold	GroundSkin result	Basis
Interface current < 1.0 mA; target ≤ 0.2 mA	0.100 mA nominal; 0.133 mA at the lowest-resistance bound	100.1 kV / 1.00 GΩ; EPA §2
No arc contacts suit or astronaut	Only the wand tip, 866 mm from the glove, touches the lander; tip spark ≤ 5 mJ	Tip capacitance ≤ 1 pF; EPA §6
Discharge within 30 s	Below 100 V in 1.4 s nominal; 5.5 s to 10 V at the slowest corner	τ = 0.20 s; EPA §2
Mass < 20 kg	1.34 kg; 1.67 kg with 25% margin	Bill of Materials
Power	0 W; lander power and heaters not used	Fully passive

2. The problem as we modelled it

The challenge models [1] the astronaut as a 200 pF capacitor at −100 kV or more against a lander at about +100 V. That stores 1.0 J, released in nanoseconds if a glove or boot simply

touches the ladder. Jackson et al. showed why the south pole makes this worse: inside and on the lee side of shadowed craters, plasma currents fall to as little as 0.04 nA/m², while regolith conductivity drops to about 10^{-17} S/m at 100 K [2, 3]. Charge from each step therefore accumulates, and the ground offers no drain. A design that bleeds charge through boot soles into regolith cannot work there, so GroundSkin does not rely on one. It gives the charge exactly one exit, at the lander, through a known resistance, at a place we choose.

3. System architecture

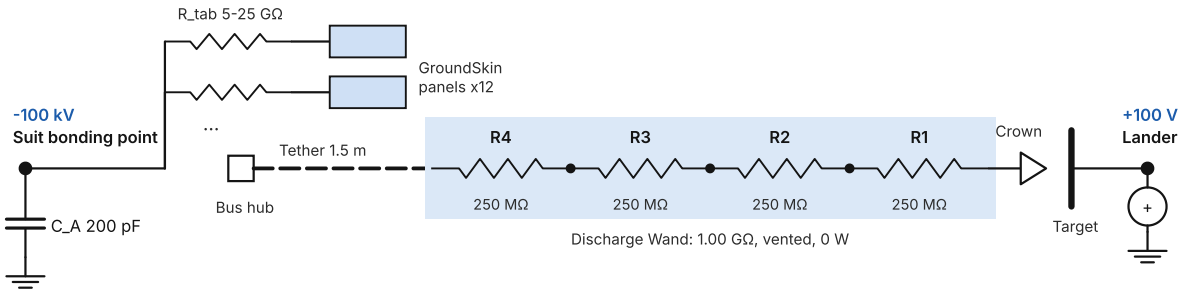


Figure 2. Electrical schematic. The suit bonding point, 12 GroundSkin panels and the tether share one node; only the wand chain (shaded) connects that node to the lander.

3.1 Discharge Wand: the only current-limiting element

The wand holds four Ohmite Maxi-Mox MOX-5N resistors, 250 MΩ ±1% each, rated 50 kV and 130.6 mm long, in series inside a G-10CR cryogenic fibreglass tube [5, 7]. Each stage carries 25.0 kV at full differential, half its rating and inside standard derating guidance [8]. The chain sits in the two outer sections of a three-section, Z-folding wand: 1,051 mm deployed, 375 × 96 × 36 mm stowed. The grip, butt cap and tether all stay at suit potential, so the glove sees no field; the gradient zone starts at hinge 1 and ends at the tip. A crown of six beryllium-copper spring fingers forms the tip and wipes through any dust film as it seats. The bore is vented and the resistors are unpotted, so no trapped gas can pass through the Paschen minimum during depressurisation. A 1.5 m coiled tether, FEP high-voltage wire inside a Vectran braid [6], connects the wand to the hip bus hub and doubles as the EVA tool tether.

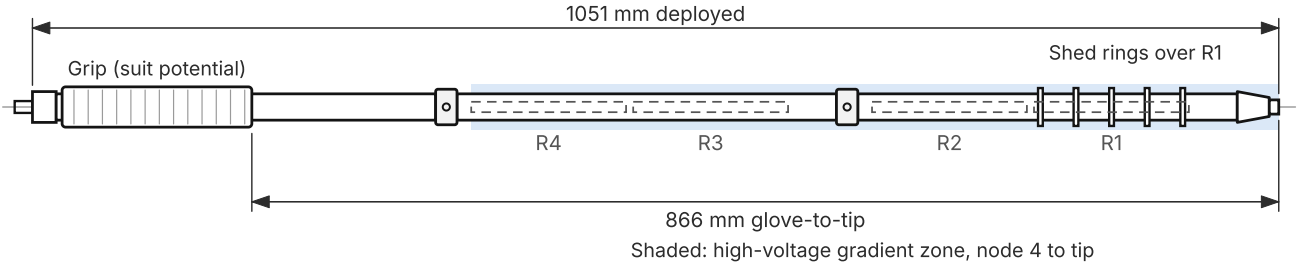


Figure 3. Discharge Wand, deployed (dimensions in mm). R1 to R4 run inside the tube (dashed). Full dimensions appear on drawing DWX-GS-002.

We chose a discrete chain over a resistive fabric as the limiting element because it can be verified: its resistance does not depend on where anything touches, it reads 1.00 GΩ on a

hand-held insulation tester before every EVA, and its four stages tolerate faults. One stage can short and the current stays under 0.2 mA; three of four can short before it reaches 1.0 mA.

Holding the resistors within their −55 °C datasheet limit at −218 °C ambient takes no power. The wand leaves the airlock warm and rides in a holster wrapped in multilayer insulation with an effective emittance of 0.03 or less. A radiative cool-down model puts it at −42 °C after eight hours in a permanently shadowed region (EPA §7). If the holster underperforms, the drift should run the safe way: thick films of the ruthenium-oxide family typically rise in resistance as they cool, which lowers current and only lengthens the discharge. The corner analysis still covers a 25% fall.

3.2 GroundSkin: a charge-managed outer layer

DragonWorx builds the Lunar Mobility Augmentation Layer (LMAL), an outer wear-over layer with energy-return leg joints and stowable panels on the forearms, chest, thighs and shins; Appendix A, in the supplemental files, describes it in full. GroundSkin adds a 25 µm carbon-nanotube-loaded polyurethane topcoat to those panels, tuned to a sheet resistance of 1 to 5 × 10^9 Ω/sq, within NASA's static-conductive class [4]. Each of the 12 panels connects to a PTFE-insulated bus only through a 100 × 20 mm bleed tab of the same coated fabric, folded to the body side under PTFE film. The tab's resistance, $R_s \times L / W = 5\ R_s$, works out to 5 to 25 GΩ. The bus runs to a hub on the hip harness, which bolts to the suit's bonding attachment point with a short strap. If no LMAL is worn, a 0.45 kg vest-and-sleeve carrier provides the same panels.

The layer does three jobs. First, it turns the most exposed surfaces into a single equipotential body, so that the wand drains panel charge too instead of leaving isolated patches that could brush-discharge later. Second, it softens inadvertent contact: if a forearm or shin panel touches the ladder before the wand does, the bleed tab caps the current from the rest of the suit at 100.1 kV / 5 GΩ = 0.020 mA, and the panel's own share of the charge, about 0.25 µC for a forearm panel, drains through the sheet as a resistive discharge instead of an arc. Third, it enlarges the conducting area the suit presents to the ambient plasma, which Jackson et al. recommend for limiting charge build-up in the first place [2].

3.3 Lander Discharge Target

The target is a 200 × 200 × 3 mm 6061-T6 plate with a spun capture cone (70 mm mouth, 14 mm seat, 25 mm deep), mounted vertically beside the ladder at about 1.15 m and bolted to the lander bonding attachment point. A gloved hand can find the cone by feel. The vertical face and horizontal cone axis shed settling dust, and the crown fingers wipe through whatever remains. Mass is 0.43 kg; it needs no heater and no power.

---

4. Why the arc never reaches the suit

Geometry. The crown is the only thing that touches the lander first, and it sits 866 mm from the glove. Its node capacitance stays at or below 1 pF, so the only unlimited discharge at contact, the crown's own charge, carries at most ½ × 1 pF × (100.1 kV)² = 5 mJ, and it lands on the target plate.

Starved arcs. Behind the crown, the chain limits available current to 0.1 mA. A vacuum arc needs a cathode spot, which takes currents thousands of times larger [11]. The challenge notes that dust increases arc distance; GroundSkin does not need to prevent a dust-triggered breakdown in the last millimetres before contact, because such a breakdown can only drain the crown's 1 pF and then goes out.

Contact transient. At the instant of contact, the chain's internal nodes cannot change potential instantly, so the tip stage briefly carries far more than its 25 kV share. Our ladder-network simulation puts up to 94 kV across R1, staying above 50 kV for 0.76 ms (EPA §3). We designed for that: R1 serves as the designated hold-off stage, with 130.6 mm of body length (7.2 kV/cm, a stress that published vacuum flashover data suggest it can hold but Phase II must confirm [9, 10]) under five PEEK shed rings. Meanwhile the suit side sees nothing abrupt. Interface current rises smoothly to a 0.097 mA peak at 5 ms, and its capacitive component at contact measures 0.0007 mA. We considered grading capacitors along the full chain and rejected them, because they would push 0.2 to 0.9 µC of fast charge straight through the suit interface.

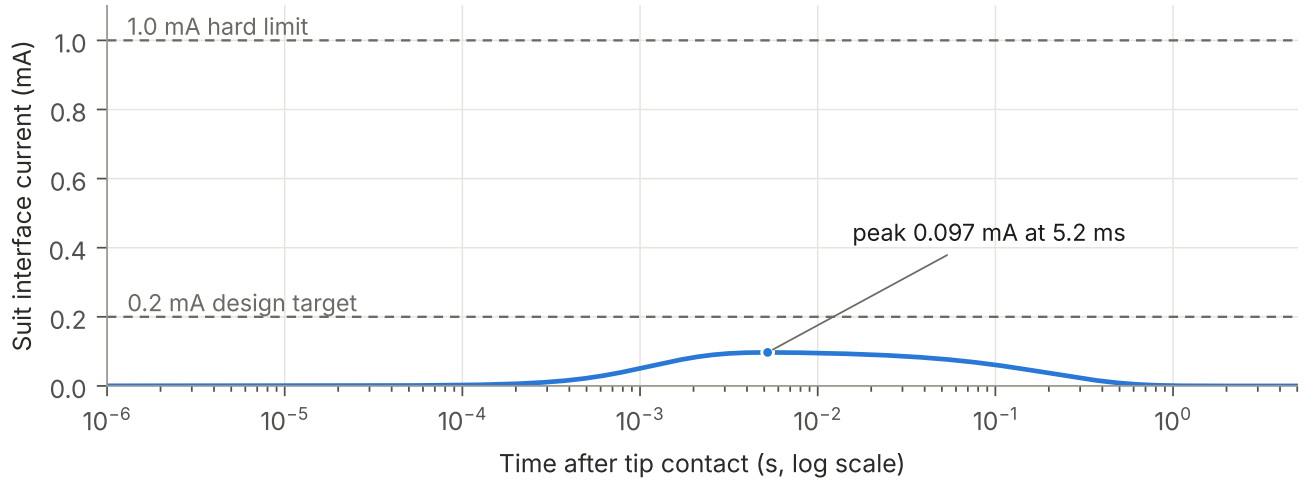


Figure 4. Suit interface current after tip contact, from the ladder-network model with a 200 pF astronaut at −100 kV. The current never approaches the design target.

5. What we left out, and why

Option	Why GroundSkin does not use it
Bleeding charge through conductive boot soles	Regolith near 10^{-17} S/m at 100 K cannot carry it away [2, 3].
Corona points to shed charge	Corona is a gas discharge; at lunar surface pressure there is no gas to ionise.
A resistive suit fabric as the limiter	Current would depend on where the suit touches; it cannot be verified before an EVA.
Potted resistor chain	Voids in potting pass through the Paschen minimum as the airlock depressurises.
Full-length grading capacitors	They move 0.2 to 0.9 µC of fast charge into the suit interface.

Two ideas stay in as optional Phase II trades, not credited in the compliance case: field-emission edge strips on the LMAL wing trailing edges, to relieve strong negative charge into vacuum, and overshoe soles matched to regolith's triboelectric position, which Jackson et al. propose to cut charging per step [2].

6. Environmental compliance

Condition	How GroundSkin meets it
0.165 g	Passive and gravity-independent; low gravity makes the 10 s hold in the cone easier.
−361 to −31 °F (−218 to −35 °C)	G-10CR, PEEK, PTFE and BeCu all keep their properties at cryogenic temperatures [7]. The resistors stay above −55 °C in the MLI holster. FEP wire and the topcoat get cryogenic qualification in Phase II.
Dust, 0.02 to 10 µm	Dust lacks the conductivity to create leakage paths. The wiping crown, sealed bore, shed rings, 0.5 mm hinge clearances and vertical target face handle it mechanically.
Four EVAs over 10 days	No consumables. A pre-EVA insulation-tester reading (1.00 GΩ ± 5%) and a visual check confirm readiness.
Worst-case 30 s discharge	Completes in 5.5 s at the slowest corner. Even 100.1 kV held across the chain for 30 s deposits 75 J per stage, a rise of a few kelvin.
Suit and lander interfaces	One strap to the suit bonding point and one stud to the lander bonding point. No change to suit material.

7. Phase II verification plan

Phase II tests the assumptions this analysis leans on hardest, in order of risk. (1) A 150 kV impulse test of the R1 stage in vacuum, clean and with JSC-1A simulant on the tube. (2) Resistance of the MOX-5N stages from 293 K down to 55 K. (3) Topcoat sheet resistance and crack resistance under folding at −218 °C. (4) Holster cool-down in thermal vacuum. (5) A glove-and-mock-up trial of unfolding, seating and holding the wand.

References

1. NASA Tournament Lab and CrowdPlat (2026). Lunar Grounding Challenge: challenge description and submission requirements. work.crowdplat.com/challenge/lunar-grounding-challenge
2. Jackson, T. L., Farrell, W. M., Killen, R. M., Delory, G. T., Halekas, J. S., and Stubbs, T. J. (2011). Discharging of roving objects in the lunar polar regions. *Journal of Spacecraft and Rockets* 48(4), 700–704. doi:10.2514/1.51897
3. Carrier, W. D., Olhoeft, G. R., and Mendell, W. (1991). Physical properties of the lunar surface. In Heiken, G., Vaniman, D., and French, B. (eds.), *Lunar Sourcebook*. Cambridge University Press. (Regolith conductivity as cited in [2].)
4. NASA (2022). NASA-HDBK-4002B, *Mitigating In-Space Charging Effects: A Guideline*.
5. Ohmite Mfg. Co. Maxi-Mox high-voltage thick-film resistors (MOX-5N: 50 kV, 130.56 mm, −55 to +210 °C) and Slim-Mox datasheet.
6. Daburn Electronics & Cable. 2476 series FEP high-voltage wire, 50 kV DC, −65 to +200 °C.
7. NIST Cryogenics Material Properties: G-10 CR fiberglass epoxy. trc.nist.gov/cryogenics/materials
8. NSWC Crane, SD-18. Resistor derating guidelines.
9. Miller, H. C. (1989). Surface flashover of insulators. *IEEE Transactions on Electrical Insulation* 24(5), 765–786.
10. Latham, R. V. (ed.) (1995). *High Voltage Vacuum Insulation: Basic Concepts and Technological Practice*. Academic Press.
11. Anders, A. (2008). *Cathodic Arcs: From Fractal Spots to Energetic Condensation*. Springer.