LUNAR SPLINT DESIGN CHALLENGE

Student Project Brief · Habitat Use Only · 3D Printing Medical Devices for the Moon

★ HABITAT-ONLY SCOPE — READ THIS FIRST

Your splint is designed exclusively for use inside the pressurized lunar habitat.

But you DO need to design for:

- ✓ Long-term wear in a shirt-sleeve environment (~20°C, normal humidity)
- ✓ A patient living and working in tight habitat quarters for weeks to months
- ✓ Self-application and removal — the crew may have no trained medical professional
- ✓ Minimizing mass (filament launched at ~$1M/kg) while maximizing function
- ✓ On-demand custom fabrication from a habitat-based FDM/SLA printer

1. MISSION CONTEXT

The year is the near future. A small crew of six astronauts is living in a pressurized lunar base. They are months into a long-duration mission when one of the crew sustains a fracture or ligament injury. There is no hospital. The next Earth-return opportunity is weeks away at minimum. The base has a compact 3D printer, a supply of medical-grade filament, medical wraps, Velcro, tape, and limb-scanning capability with an x-ray and an ultrasound. You are the engineer back on Earth who must design the splint that gets transmitted to the printer and fabricated within hours of the injury.

Your splint will be worn continuously — day and night — in a habitat where the astronaut sleeps, exercises, prepares food, conducts experiments, and performs maintenance tasks. It must work across the full recovery period: from acute immobilization in the first days, through the swelling phase of the first weeks, into the rehabilitation phase that may last months.

2. WHY THE MOON STILL CHANGES EVERYTHING

Even inside the habitat, the lunar environment imposes constraints that make this a fundamentally different design problem from an Earth splint.

1/6 Gravity

Axial bone load is ~83% lower than Earth. Lateral and torsional forces from stumbling in the habitat remain significant. Gait is bouncy and different — the patient loads the limb in unfamiliar patterns. Your stiffness calculations should reflect lunar mechanics, not Earth physiology.

Bone Density Loss

Astronauts lose 1–2% bone mineral density per month during transit. A crew arriving after a 6-month transit may have 6–12% lower bone density than a healthy Earth patient. This affects both fracture mechanics and healing. Callus formation may be impaired. Your splint must account for an extended immobilization period and continued stress-fracture risk even after the primary injury heals.

No Hospital for Weeks

Earth-return is not a quick option. Your splint must be wearable, manageable, and adjustable for the entire healing arc — potentially 8–12 weeks for a fracture. The crew member may be removing and re-applying it alone, possibly with one functional hand.

Controlled Habitat Environment

The habitat is pressurized at roughly Earth sea-level pressure and maintained at ~18–22°C. This is an ADVANTAGE for habitat-only design — you can use materials like TPU that might become brittle in surface cold. Humidity, hygiene, and skin health over weeks of wear now become your primary environmental challenge instead of temperature extremes.

3. INJURY SCENARIOS — SELECT ONE

Choose the injury your team will design for. Your entire rationale, design geometry, and innovation feature must be appropriate for this specific injury and its biomechanics.

Injury	Site	Habitat Risk Factor	Difficulty
Stress fracture	Tibia / fibula / metatarsals	HIGH — bone density loss	Intermediate
Acute fall fracture	Wrist, forearm, ankle, clavicle	HIGH — habitat furniture + equipment	Beginner–Intermediate
Finger fracture / dislocation	PIP / DIP joints	MOD–HIGH — fine motor tasks	Beginner
Lateral ankle ligament tear	Lateral ankle	MODERATE — uneven habitat flooring	Intermediate
Achilles partial tear	Posterior ankle	MODERATE — repetitive movement in habitat	Advanced

Note on habitat-specific risk: In the habitat, injury mechanisms differ from EVA. Falls occur from low furniture, ladder slips, or sudden stumbles in microgravity-adapted muscle patterns. Fine motor tasks at workbenches *introduce finger and wrist risk. Repetitive movement during exercise sessions (required daily to counter bone/muscle loss) loads ankles and feet. Keep in mind the injury might have occurred during an EVA outside of the habitat.*

4. DESIGN REQUIREMENTS

Your design must satisfy all six requirements. Address each explicitly in your biomechanics rationale.

1. **Adequate immobilization** for the chosen injury in 1/6 gravity — account for altered force mechanics.
2. **Printable on a habitat FDM or SLA printer** using ABS, PLA, or TPU for prototyping. Specify which flight-grade material (PEEK, TPU, CF-PEEK) you would use on the Moon and why.
3. **Long-term habitat wearability** — the patient wears this for weeks. Skin contact, hygiene, ventilation, and one-handed operation must be considered. Also consider skin breakdown.
4. **At least one lunar-specific innovation** (A–E, see Section 5) — integrated into the design, not just mentioned.
5. **Material justification** against biocompatibility, long-term skin contact, sterilization/cleaning, and habitat thermal requirements.
6. **Mass budget:** estimate filament mass in grams and calculate its equivalent launch cost at ~$1M/kg. Justify why the mass is worth it versus a simpler alternative.

5. REQUIRED LUNAR-SPECIFIC INNOVATIONS

You must incorporate at least one innovation from the table below. Earth splint copies will not be accepted — your design must solve a problem specific to living and healing on the Moon.

Code	Innovation
A	**Swelling-Adaptive Lattice** Variable-density gyroid or honeycomb infill that compresses gently as post-injury swelling occurs — no repeated manual adjustments by crew members who may not be medical professionals.
B	**Single-Piece Ratchet Closure** No loose parts, no screws, no Velcro. A printed friction-lock geometry the patient can operate one-handed. Critical when the injured person may need to remove the splint alone for hygiene.
C	**Rehab-Progressive Locking** Full immobilization when locking pins are in place; controlled range-of-motion when pins are removed. One splint covers the entire recovery arc without a second device.
D	**Thermal Phase Design** A TPU lattice or shape-memory element that flexes slightly when warm (habitat ~20°C) and stiffens when briefly cooled with a cold pack for acute immobilization. Both states must immobilize adequately.
E	**Integrated Hygiene Features** Fenestrations (openings) and ventilation channels designed to allow cleaning, skin inspection, and moisture management during weeks of continuous wear — a major unaddressed problem on Earth splints too.

Combining innovations is encouraged and rewarded

Example: A wrist splint with a single-piece ratchet closure (B) AND ventilation fenestrations for hygiene (E).

Example: An ankle splint with a rehab-progressive locking mechanism (C) AND swelling-adaptive lattice in the padding layer (A).

Strong designs weave innovations into geometry rather than bolting them on as afterthoughts.

6. MATERIALS FOR HABITAT USE

The habitat printer is your fabrication tool. Prototypes can use any common filament — your final design specification must argue for a flight-grade material appropriate to habitat (not EVA surface) use.

Material	Prototype	Habitat Flight Use	Key Habitat Advantage	Watch Out For
PLA	✓ Yes	No	Easy to print; good for early concepts	Brittle; degrades with humidity over months
ABS	✓ Yes	No	Better impact strength than PLA	Warps; fumes require ventilation in habitat
TPU	✓ Yes	Preferred (flexible layer)	Skin comfort; absorbs shock; stays warm in habitat	Verify durometer — too soft loses immobilization
PEEK	Specialist printer	Gold standard	Biocompatible; radiation-stable; long-duration wear	High print temp (~380°C) — needs specialist printer
CF-PEEK	Specialist printer	Advanced option	Lightest high-strength option; extreme rigidity	Higher print complexity; less flexible design options

Habitat advantage: Because the splint never goes outside, you are not designing for −173°C. TPU — which becomes brittle below −40°C on the surface — is an excellent habitat-use material for flexible padding and closure elements. PEEK remains the gold standard for structural components requiring biocompatibility and long-term wear.

7. LUNAR BIOMECHANICS — WHAT YOU NEED TO KNOW

Gravity and Load Distribution

- Axial load on long bones is ~83% lower than Earth — your splint does not need to resist the same compressive forces
- Lateral and torsional forces from stumbles in the habitat remain close to Earth values
- Splint stiffness can be reduced along the bone axis but lateral/torsional reinforcement is still critical
- Habitat gait is different — astronauts adapt to 1/6g with longer-stride movement patterns that load joints differently
- Muscle atrophy during transit changes force transmission patterns through the injured limb

Bone Density and Healing

- 1–2% bone mineral density (BMD) loss per month during transit; arrival BMD may be significantly reduced
- Callus formation — the biological process that bridges a fracture — may be impaired in microgravity
- Longer immobilization periods are likely compared to Earth clinical guidelines
- Re-fracture risk remains elevated; stress-fracture risk persists even after the primary injury heals
- Your splint must accommodate this extended healing arc — stiffness that cannot be modulated over weeks is a design failure

Habitat Wear Considerations (Unique to This Scope)

- The patient performs daily exercise to counteract further BMD loss — the splint must not prohibit this entirely
- Hygiene: skin kept under a splint for weeks without adequate ventilation develops pressure sores, dermatitis, and bacterial/fungal infections — a serious medical problem in an isolated habitat
- The patient may be alone when needing to remove the splint for hygiene — one-handed operation is a genuine requirement
- Sleep: the splint is worn through the sleep cycle — sharp edges or pressure points become serious over days
- Consider that the crew member must continue contributing to mission tasks despite the injury

8. THINKING INNOVATIVELY — QUESTIONS TO PUSH YOUR DESIGN

Use these questions to move beyond a conventional splint. Strong projects re-examine assumptions.

Challenge the form factor Does a splint have to look like a splint? Could a wrist splint integrate with a glove-like structure the crew	**Challenge the user model** The 'user' is not a compliant Earth patient who can see a doctor if anything goes wrong. They are an astronaut

member already wears for lab work? Could an ankle splint use a boot-liner geometry that slots into habitat footwear?

Challenge the material distribution

FDM printers can vary infill density within a single print. Where does your splint need to be rigid? Where flexible? Where ventilated? A uniform shell is almost never the optimal answer — map the functional zones of the splint and design each deliberately.

Challenge the duration assumption

Earth splints are designed for a clinic visit in a week. Yours may be worn for 10 weeks. What fails first on an Earth splint at 10 weeks? Design against that failure mode, not just immobilization.

in a high-stakes environment, probably performing tasks one-handed. What does they need to be able to do despite the injury? Design to enable function, not just restrict movement.

Challenge what a 3D printer enables

A 3D printer can produce geometries that are impossible to manufacture any other way. Lattice structures, internal channels, undercut features, gradient density. What would you design if you were not limited to what you could cut from a flat sheet of fiberglass? Start there.

Look at adjacent fields

Exoskeletal rehabilitation robots use progressive resistance. Orthotics use dynamic carbon-fiber energy return. Pressure garments manage edema through graded compression. What principle from outside orthopedics could solve a problem your splint faces?

Design provocation: What if the crew member needs to perform an emergency repair task with the injured limb?

This is not hypothetical — in a small crew, every person has critical roles. A fractured wrist that completely prevents any fine motor function could jeopardize the mission.

Can your splint design allow partial controlled function (grip strength, button pressing) while still protecting the fracture site?

This is the kind of design tension that makes a strong project — and that no Earth splint ever had to solve.

9. DELIVERABLES

01	**Biomechanics Rationale** 1–2 pages. How does the Moon (and specifically the habitat environment) change your design decisions? Address gravity, bone density, long-term wear, and the specific biomechanics of your chosen injury.
02	**Annotated Concept Sketch** Every design decision is labeled with its reason. Don't draw unlabeled shapes — explain why each feature exists. Your innovation feature must be clearly indicated.
03	**CAD Model or Detail Drawing** Geometry, wall thickness, infill zones, closure mechanism, and material specification. If using CAD software, include at least one cross-section showing internal structure.
04	**Mass and Print-Time Estimate** Estimate filament mass in grams. Calculate equivalent launch cost. Calculate estimated print time. Justify both against the clinical value of the custom fit.

05	**Design Review — 5 minutes** Present as if briefing the lunar base medical officer. They will ask hard questions about why your design choices are better than a simpler alternative. Be ready to defend every decision.

10. GRADING RUBRIC (100 points)

Category	What we are looking for	Points
Biomechanics Accuracy	Does the design correctly address 1/6g, bone density loss, habitat environment, and long-term wear for the specific injury chosen?	25
Novelty & Justification	Is the innovation well-reasoned, clearly described, and integrated into the design — not just listed?	25
Design Completeness	Are geometry, wall thickness, closure mechanism, infill strategy, material selection, and fit all addressed? No critical gaps.	20
Mass & Printability	Realistic filament mass estimate; print time considered; material justified for habitat use.	15
Presentation & Defense	Clear communication, confident answers under questioning, presented as if speaking to the crew medical officer.	15

11. RESEARCH RESOURCES

Use these resources to ground your design decisions in real science and engineering. Go to primary sources — do not cite a YouTube video when the NASA technical report is freely available.

Space Medicine & Bone Loss

→ NASA Human Research Program — Bone Loss Evidence *Primary NASA risk evidence reports on musculoskeletal health in spaceflight*

→ Sibonga et al. (2019) — Bone loss in long-duration spaceflight, NASA JSC *Key paper on bone density changes in astronauts — cite specific percentages from here*

→ LeBlanc et al. — Skeletal responses to space flight (NASA Technical Reports) *Search NASA Technical Reports Server for peer-reviewed bone physiology data*

→ NASA Technical Reports Server (NTRS) *Free archive of all NASA research — search 'fracture', 'musculoskeletal', 'bone mineral density'*

Lunar Habitat & Environment

→ NASA Artemis Architecture — Lunar Gateway and Surface Systems *Understand the habitat context your splint will live in*

→ ESA Moon Village — Habitat Design Considerations *Alternative habitat design approaches and constraints*

→ NASA SP-2010-3407 — Human Integration Design Handbook (HIDH) *Authoritative guide to human factors in spacecraft — relevant to wearable device design in confined habitats*

Remote & Space Medicine

→ ISS Medical Operations — crew health management protocols *Understand the medical reality — crews are not surgeons; the patient may self-administer care*

→ Space Medicine Association — Journal of Space Medicine *Professional body for space medicine — review their resources and publications*

→ Kerstman et al. (2012) — Space Adaptation Back Pain: A Systematic Review, Aviat Space Environ Med *Example of how spaceflight-specific injury patterns differ from terrestrial medicine*

3D Printing Materials — PEEK, TPU, and Biocompatibility

→ Invibio PEEK-OPTIMA Technical Data Sheet *Medical-grade PEEK specifications — cite thermal, mechanical, and biocompatibility data from here*

→ ISO 10993 — Biological Evaluation of Medical Devices *The international standard for biocompatibility — understand what your material must meet*

→ PEEK in orthopaedic implants — systematic review (PubMed) *Search for literature review papers on PEEK clinical performance — basis for flight material selection*

→ Yang et al. (2022) — TPU-based 3D-printed orthotics: a review, Polymers *Literature on TPU in wearable orthopedic devices — key for your flexible layer justification*

3D-Printed Splints & Orthotics — Earth Baseline

→ Toth et al. — 3D-printed splints in emergency medicine: a clinical review *Search PubMed for recent clinical trials — understand what already works and what fails on Earth before designing for space*

→ e-NABLE Community — open-source 3D-printed prosthetic and orthotic designs *See what is actually printable on FDM printers at field locations — useful precedent for closure mechanisms*

→ Osteoid (Cortex) 3D cast — seminal design by Jake Evill (Dezeen, 2013) *Landmark concept for mesh-structure custom cast — study the lattice approach and hygiene features*

Additive Manufacturing — Lattice Structures and Topology Optimisation

→ Gyroid lattice structures in biomedical applications — literature search *Gyroid and TPMS (triply periodic minimal surface) structures are the state of the art for swelling-adaptive infill*

→ Autodesk Fusion 360 — free for students, includes lattice and topology optimisation tools *CAD software you can use to design and document your splint geometry*

→ nTopology — advanced lattice design (student access available) *Purpose-built tool for lattice and functional gradient structures — relevant if pursuing innovation C (swelling-adaptive lattice)*

→ Onshape — free browser-based CAD for students *Alternative to Fusion 360 — no download required, works in browser*

Shape-Memory Polymers (Innovation A — Thermal Phase Design)

→ Hager et al. (2015) — Shape Memory Polymers: Past, Present and Future Developments, Progress in Polymer Science *Foundational paper — understand the mechanism before designing around it*

→ Mather & Luo (2002) — Shape memory polymer research, Annual Review of Materials Research *Google Scholar search — find recent papers on SMP application in wearable medical devices*

Lunar Regolith and Habitat Safety (Context)

→ NASA — Lunar Dust Health Hazards *Even in the habitat, regolith tracked in on suits is a health hazard — relevant context for habitat safety design*

→ Taylor et al. — Characterisation of lunar regolith (NASA JSC) *Understand the physical properties of lunar dust — useful context even for habitat-scoped designs*

12. MASS BUDGET GUIDE — HOW TO CALCULATE

Every gram of filament launched to the Moon costs approximately $1,000 (at $1M/kg). Use this framework:

Step-by-step mass estimate
Step 1: Estimate your splint volume in cm³ from your CAD model or rough geometry.
Step 2: Multiply by infill fraction (e.g., 25% infill → multiply volume × 0.25 for the solid fraction, then add shell volume).
Step 3: Multiply by material density (PLA: 1.24 g/cm³ | ABS: 1.04 g/cm³ | TPU: ~1.2 g/cm³ | PEEK: 1.32 g/cm³).
Step 4: Convert to kg and multiply by $1,000,000 to get launch cost.
Step 5: Ask: is this mass justified? What is the alternative? (A pre-fabricated set of fixed-size splints in every size = far more mass.)
Typical hand splint: ~40–80g filament. Typical ankle splint: ~80–150g filament.

Strong projects show this calculation explicitly and then argue why the custom-fit, on-demand approach saves mass versus the alternative of launching a full inventory of pre-made splints. This argument is the entire justification for the habitat printer.

Mission briefing complete.

Your crew is counting on you.

Design a splint that works in the most demanding environment humans have ever inhabited. Make it light enough to justify the launch cost. Make it smart enough for the Moon.