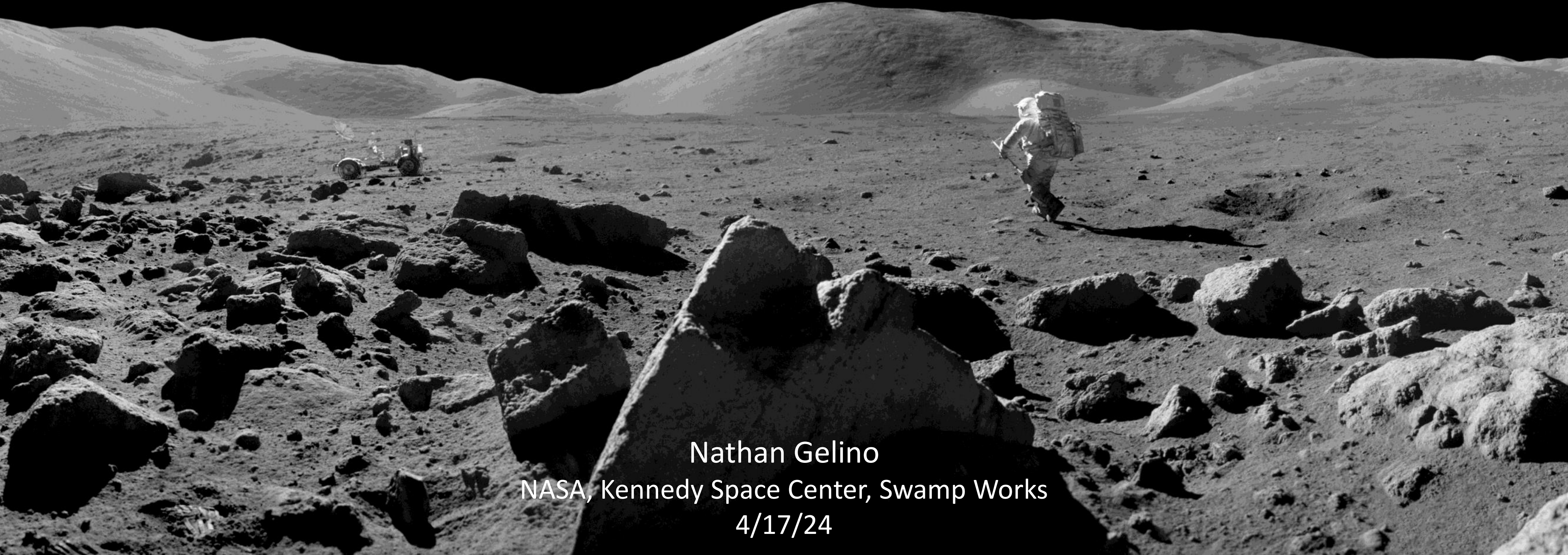
NASA

Selection, Production and Properties of Regolith Polymer Composite for Lunar Construction

2024 ASCE Earth and Space Conference



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NASA, Kennedy Space Center, Swamp Works
4/17/24

REACT

Relevant Environment Additive Construction Technology

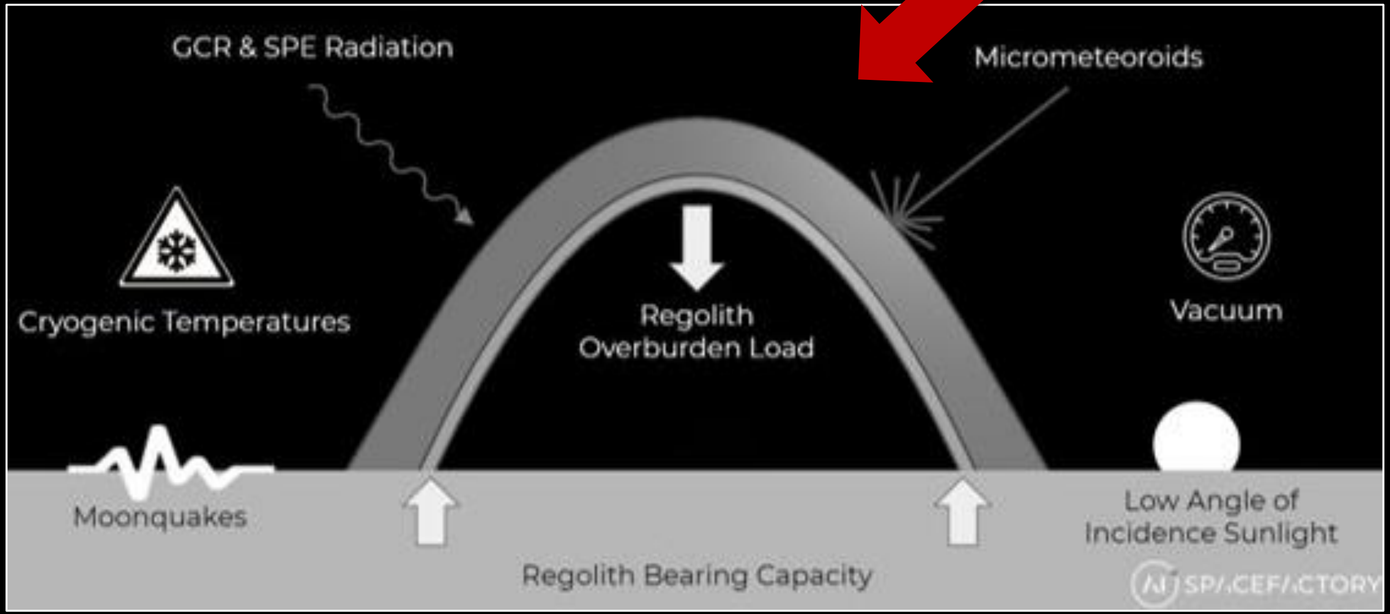
SWAMP WORKS
NASA KENNEDY SPACE CENTER

SPACEFACTORY

LERA
Consulting Structural Engineers

Project Origins and Intent

SpaceFactory won NASA' 3D Printed Habitat Centennial Challenge



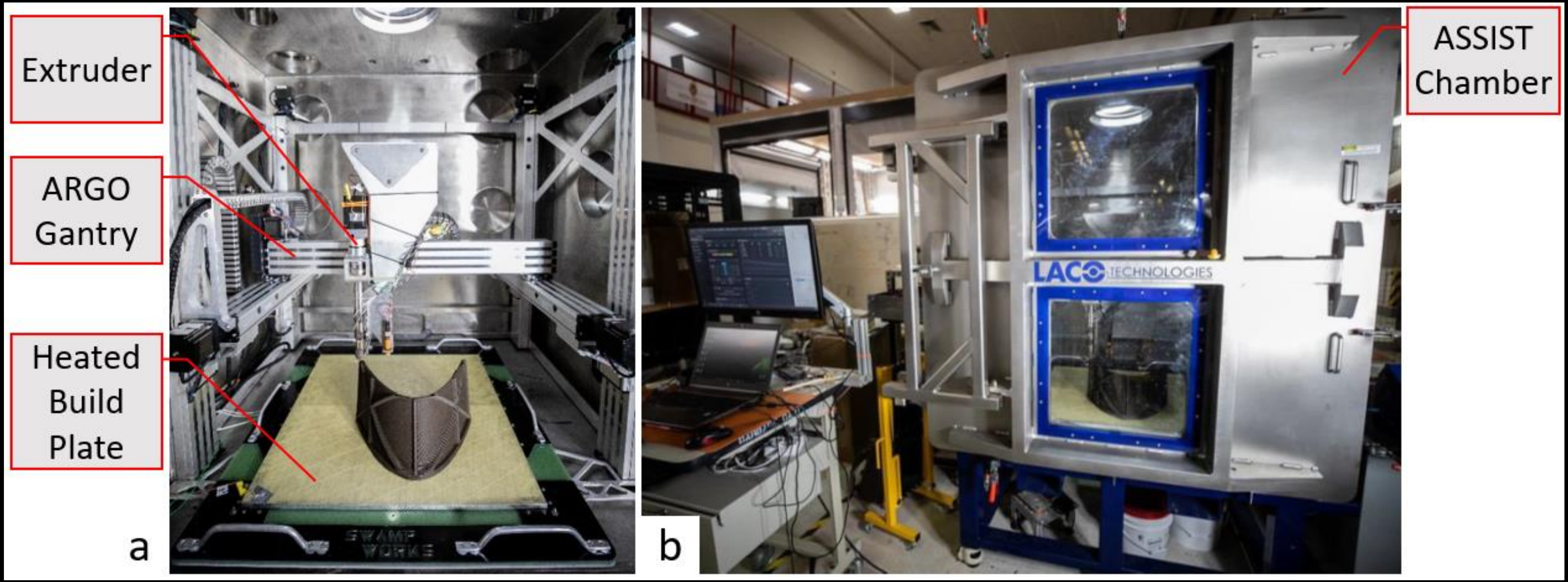
Intent is to mature this technology by exercising it in simulated lunar conditions and building a sub-scale unpressurized protective shelter

Goals and Objectives

Goal	To demonstrate construction of a civil engineered, unpressurized, protective shelter in simulated Lunar Dirty Thermal Vacuum (DTVAC) conditions using Regolith-Polymer Composites (RPC) in a Fused Granular Fabrication (FGF) additive process

Objective #1	Develop regolith-polymer composites and characterize material/strength properties of test samples printed under DTVAC
Objective #2	Develop the shelter's architectural and structural design based on protective needs, design criteria established from environmental conditions, and validation/optimization using terrestrial industry techniques
Objective #3	Demonstrate additive construction of a sub-scale protective shelter in simulated lunar conditions

Test Equipment – ARGO



Advanced GRound Operations (ARGO) Testbed

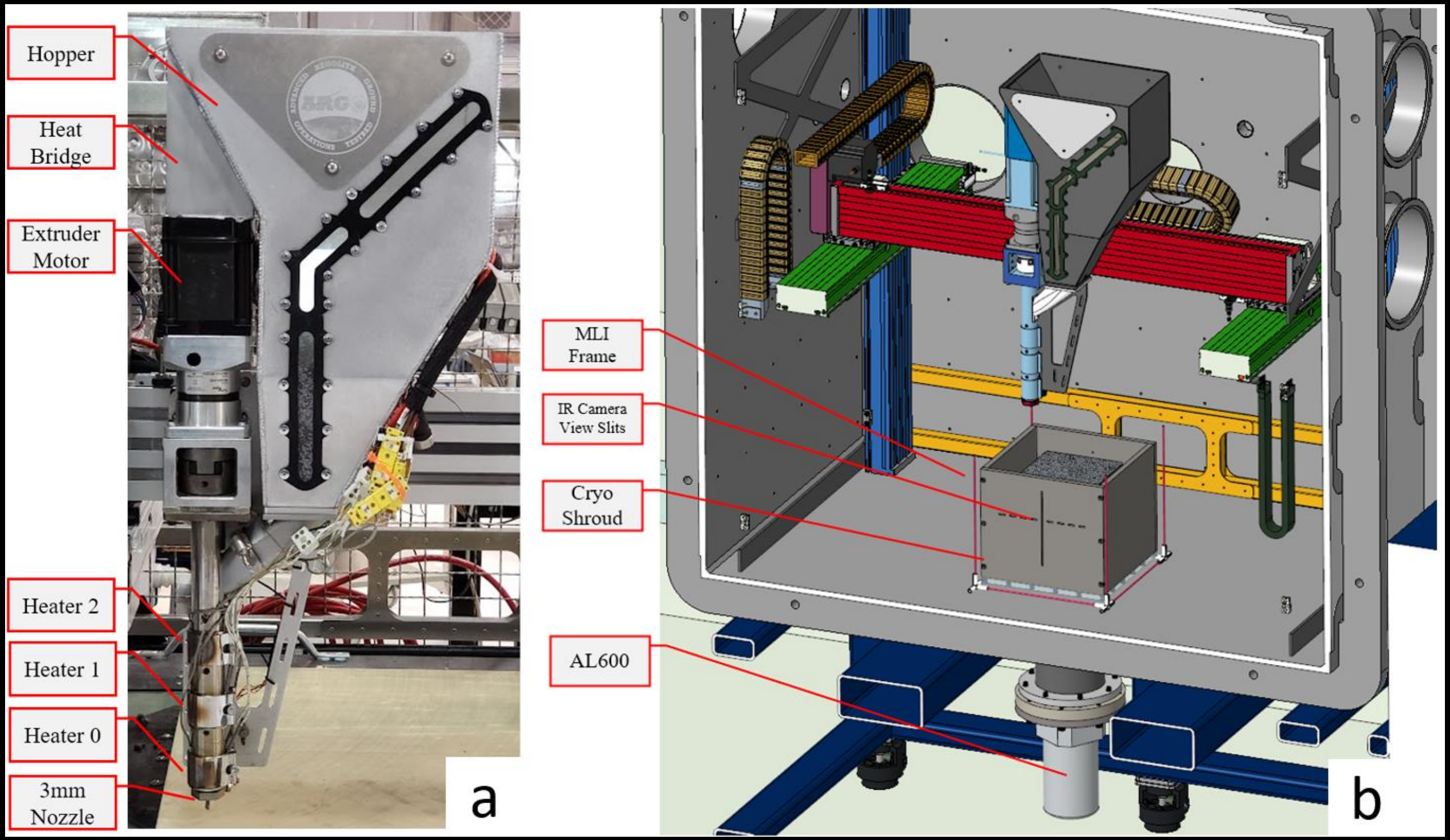
- Firmware: Klipper (open source)
- Control Board: Bigtreetech Octopus
- Gcode: Ultimaker Cura slicer software
- Manual Control and File Handling: Mainsail OS via Raspberry Pi

Atmospherically Sealed Simulator for In-situ System Testing (ASSIST) Chamber

1.5 x 1.5 x 1.2 m (w x h x d)

760 – 3.5 x 10-6 torr (~10-5 torr with ARGO installed)

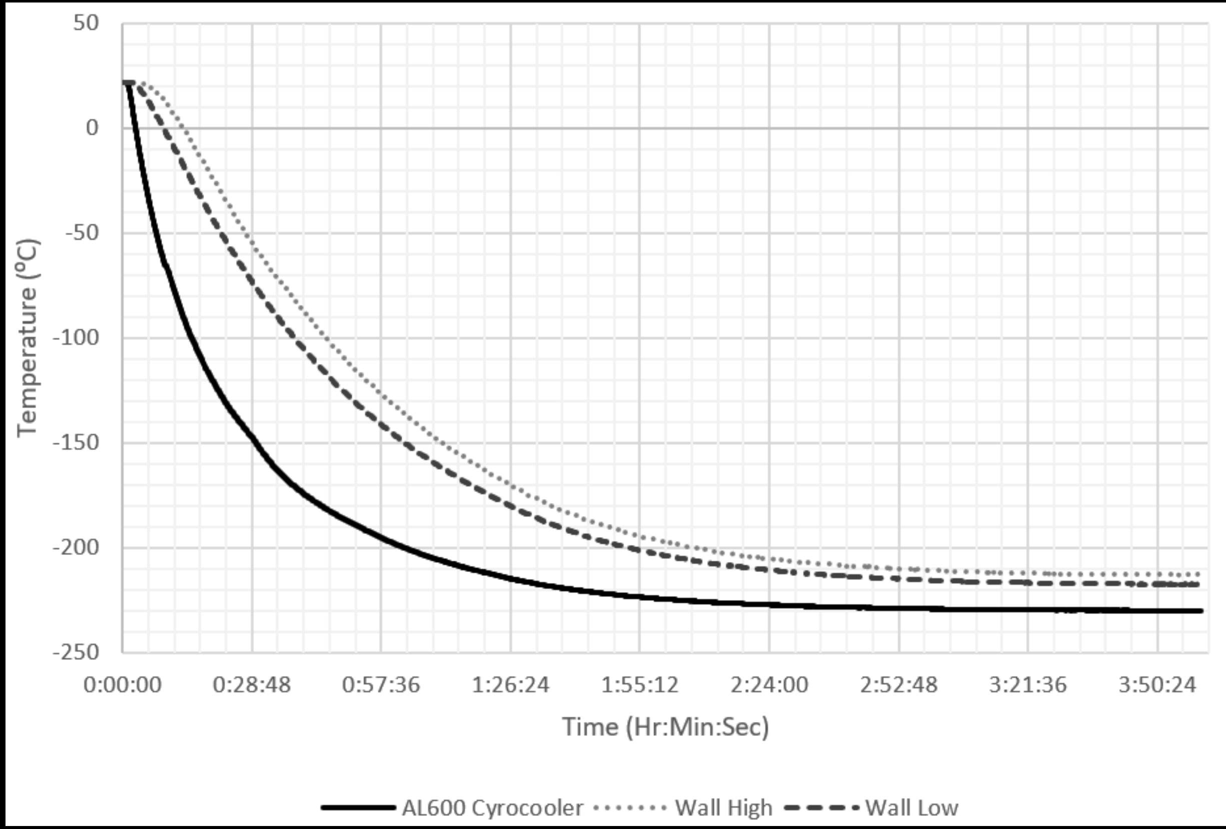
Test Equipment – Extruder and Cryo Shroud



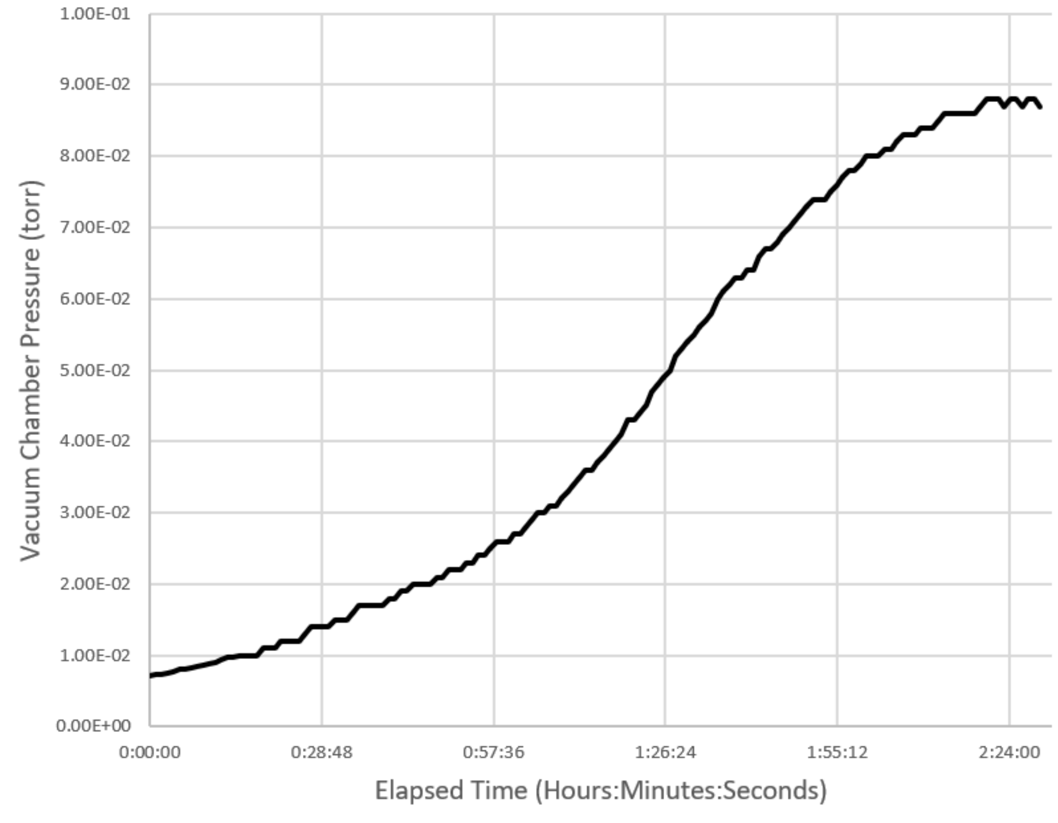
Extruder:

- 17 L of pellets
- Max Steady State Extrusion Rate: 85 mm3/s
- Typical linear speed: 25 mm/s
- BL Touch bed mesh leveling or manual
- Typical layer: 5.8 mm wide x 1.5 mm tall

Test Equipment – Typical Environments



Cooldown performance prior to print. Temperatures typically increased to -190 ° C during printing due to extruder and print heat.



Vacuum performance during print. Pressure increase is likely due to water sublimation off the thermal shroud when warmed by the extruder and print.

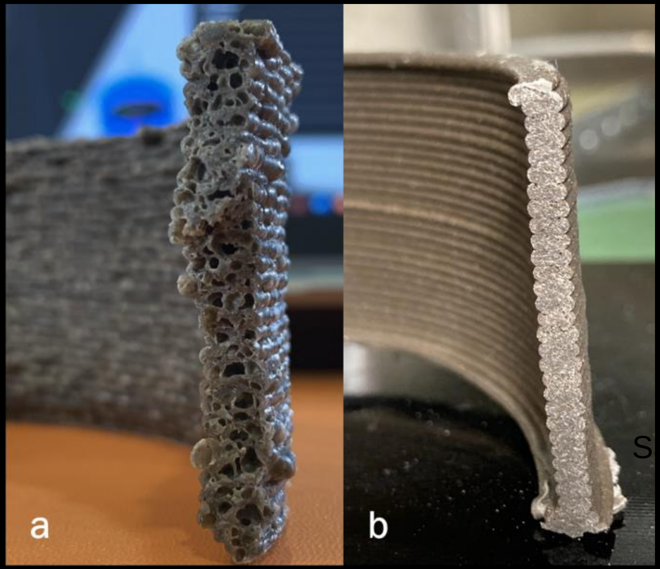
RPC Production and Formulations

Testing Phase	Simulant	Polymer	Additive	Mass Percentage (wt%)	Purpose
Alpha	BP-1	PP	Compatibilizer*	50:48:2	Initial vacuum printing feasibility testing
	BP-1	PP	-	50:50	
	BP-1	PLA	-	50:50	
Beta	BP-1	PLA	-	70:30	Evaluate effects of high simulant loading
	BP-1	PLA	-	80:20	
	BP-1	PLA	-	85:15	
	BP-1	PLA	Processing Aid**	80:18.5:1.5	Evaluate effects of a flow improver additive
	LHS-1	PLA	-	80:20	Evaluate effects of a highlands simulant

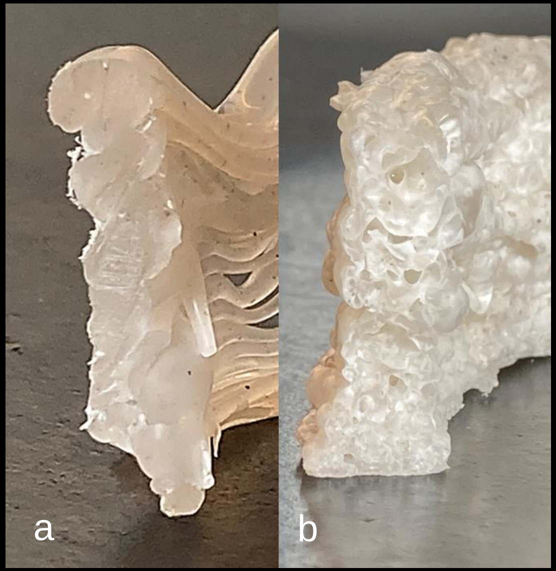
*BYK, SCONA TPPP 9212 GA
**CAI Performance, CP-L01

Alpha Initial Feasibility Tests

RPC is printed at 0.250 torr on a heated build plate



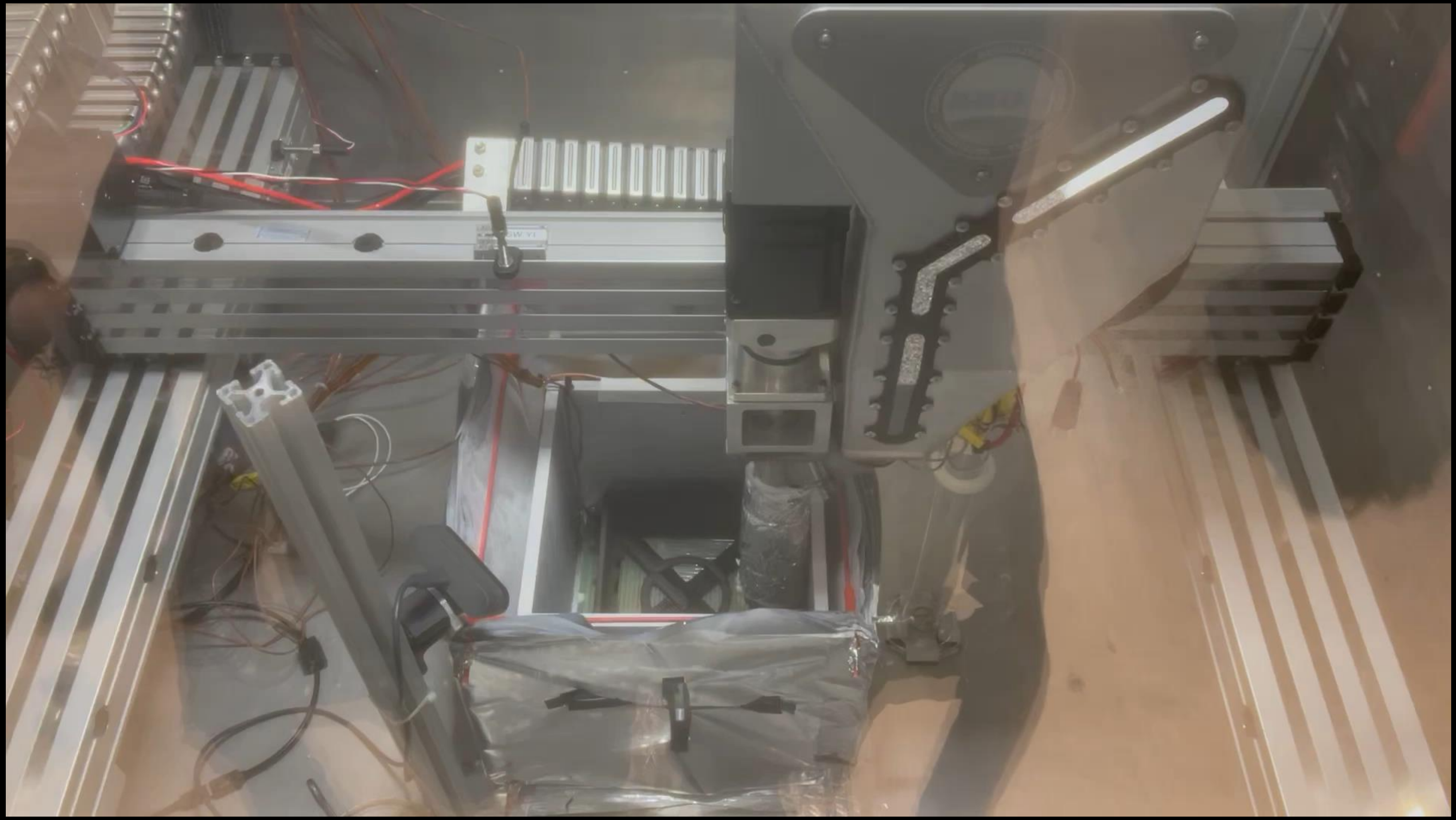
50:50 wt% BP-1:PP (a), and BP-1:PLA (b)



PP neat (a), and PP: Compatibilizer (b)

RPC pellets are produced on a compounding extruder

Beta Test Sample Construction

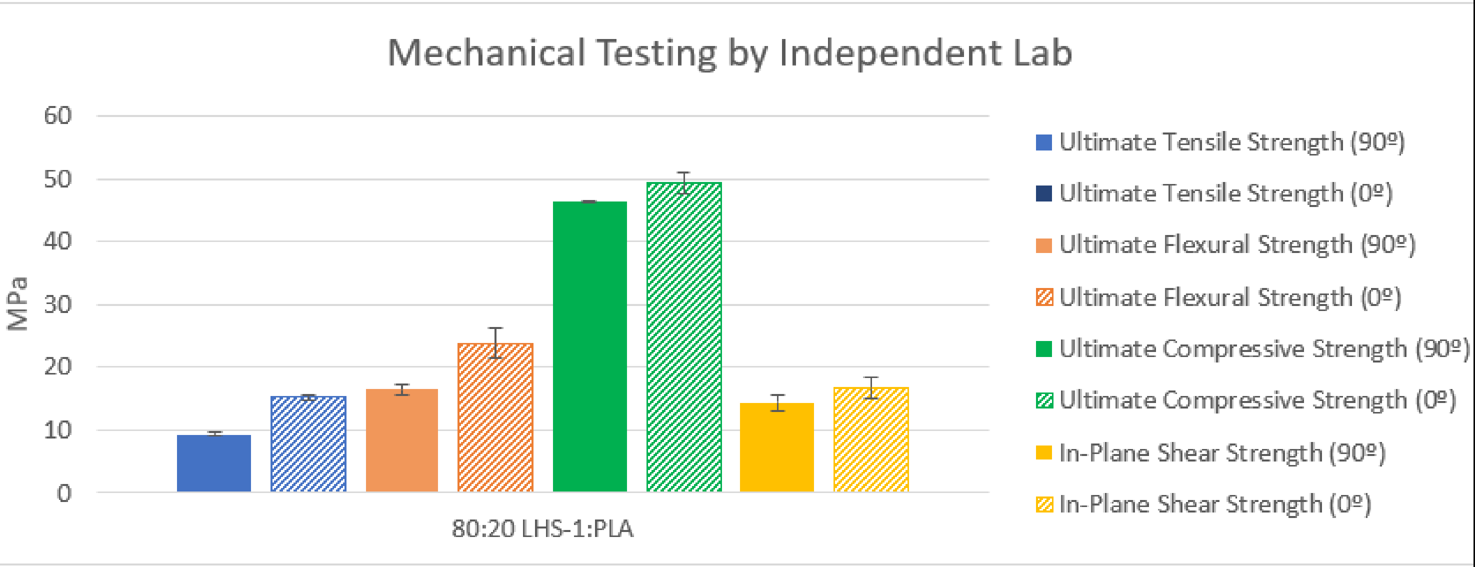


Test samples are printed in TVAC. A thermal shroud was kept below -190C. Vacuum pressure started at ~10-3 torr ends at ~0.8 torr likely due to water sublimation off the shroud when warmed by the extruder and printed structure

Printed test samples prior to water-jetting

Results Summary

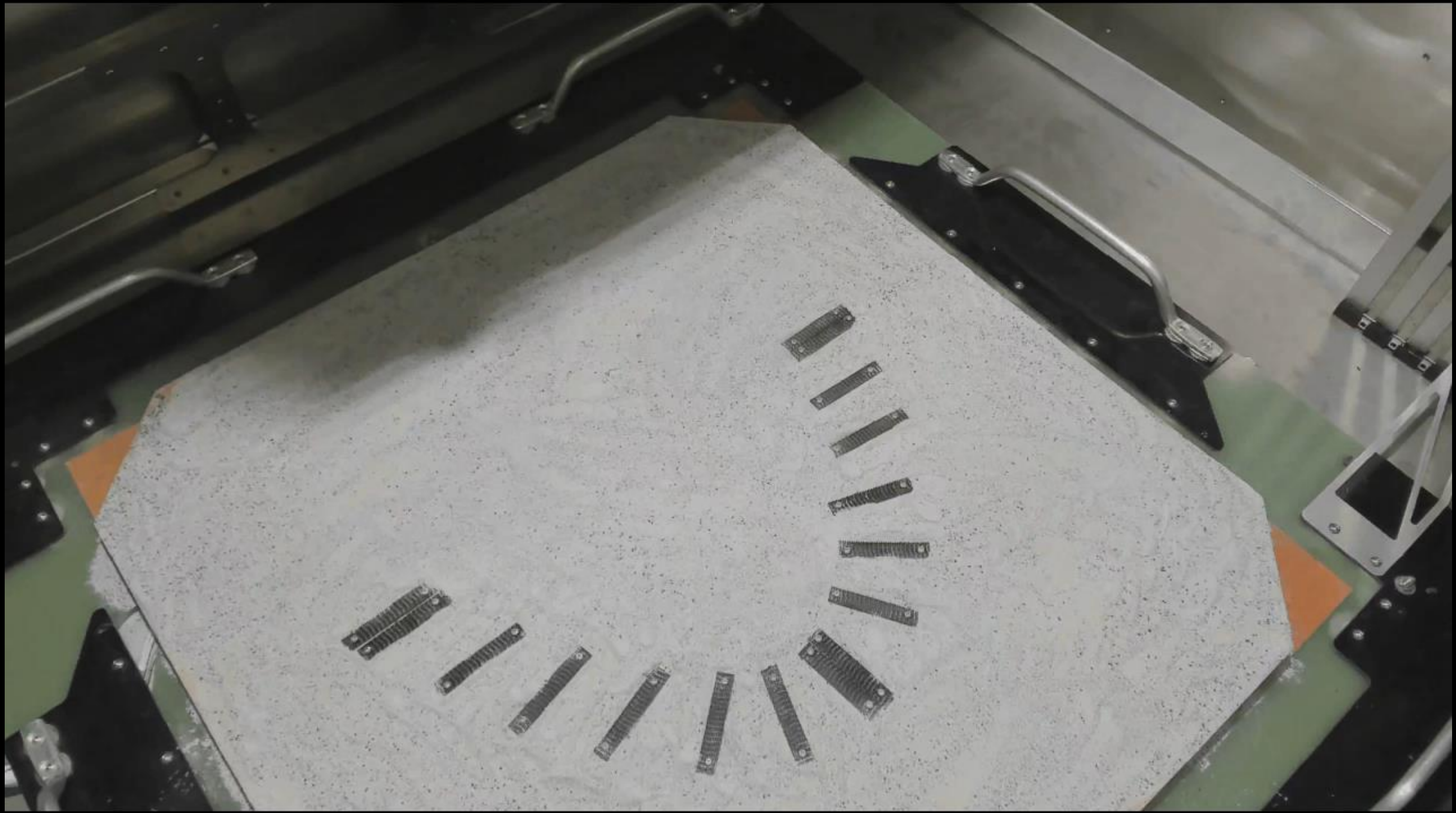
ISRU Construction of Vertical Structures Metric	Value
Energy consumption	~3 MWh/m^3
Deposition Rate	0.6 kg/hr
Construction System Mass	~175 kg
ISRU Weight Percent	75% (Targeted 80%)
Height	~0.5 m



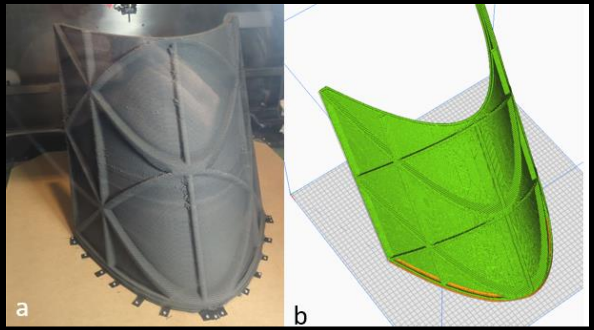
- Vacuum pressure and temperature had minimal (if any) effects on construction process and resulting material characteristics
- 80:20 LHS-1:PLA had superior properties:
  - Flexural Modulus = 5.3 Gpa @ 0˚
  - Flexural Strength = 24 MPa @ 0˚
- Typical lumber properties
  - Flexural modulus of 6-10 GPa
  - Flexural strength of 4-8 Mpa
- Typical unreinforced concrete:
  - Flexural strength 3-5 GPa.
- Potentially suitable for lunar construction
- High performance polymers will likely improve performance
- Mechanical properties across the expected lunar thermal range must be determined
- Full details on material testing and performance are provided in:

  Gelino, N. J. et al., (2024, March). "Selection, Production, and Properties of Regolith Polymer Composites for Lunar Construction." IEEE Aerospace Conference, Big Sky, MT.

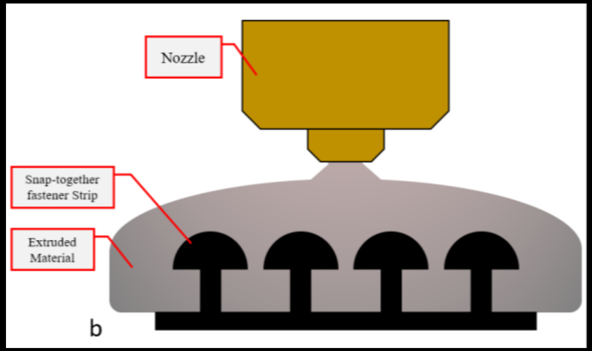
Lunar Infrastructure Asset (LINA) Construction



Second generation protective shelter is printed at ~10^{-4} torr on LHS-1 Simulant



First generation shelter design



Ground anchors secure the print

Lunar Infrastructure Asset (LINA)

Conclusions

- Basic feasibility of Regolith Polymer Composite (RPC) construction materials and systems was proven and is approaching TRL 5
- Develop small scale extruder that compounds "on the fly" and can handle 400 °C
- Explore polymer trade space and use higher fidelity simulants
- Strength property testing across lunar temp range, thermal fatigue, vacuum mass loss
- Assess potential lunar environmental impacts/contamination
- Among the highest TRL ISRU construction technologies based on TVAC demonstration/characterization, construction of complex geometry and large-scale demonstration at the Centennial Challenge
- Recommend further development towards a small scale CLPS demonstration mission

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