COSMIC
CONSORTIUM FOR SPACE MOBILITY AND ISAM CAPABILITIES

CSUN ISAM R&D: Project L.U.N.A.R.I.S.

Presenters: Hugo Vega, James Velasco, Miles Kaddoura, Ashley Mach, Noah R Turcios, and Sergio Amaya

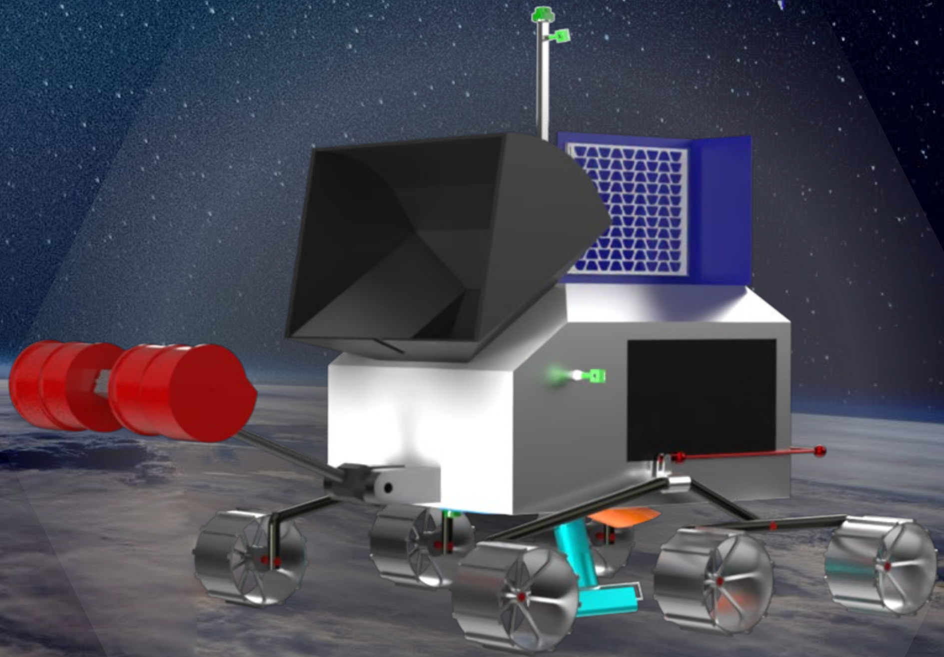
California State University Northridge

Faculty Advisor: Dr. Christoph Schaal
College of Engineering and Computer Science
Mechanical Engineering Department

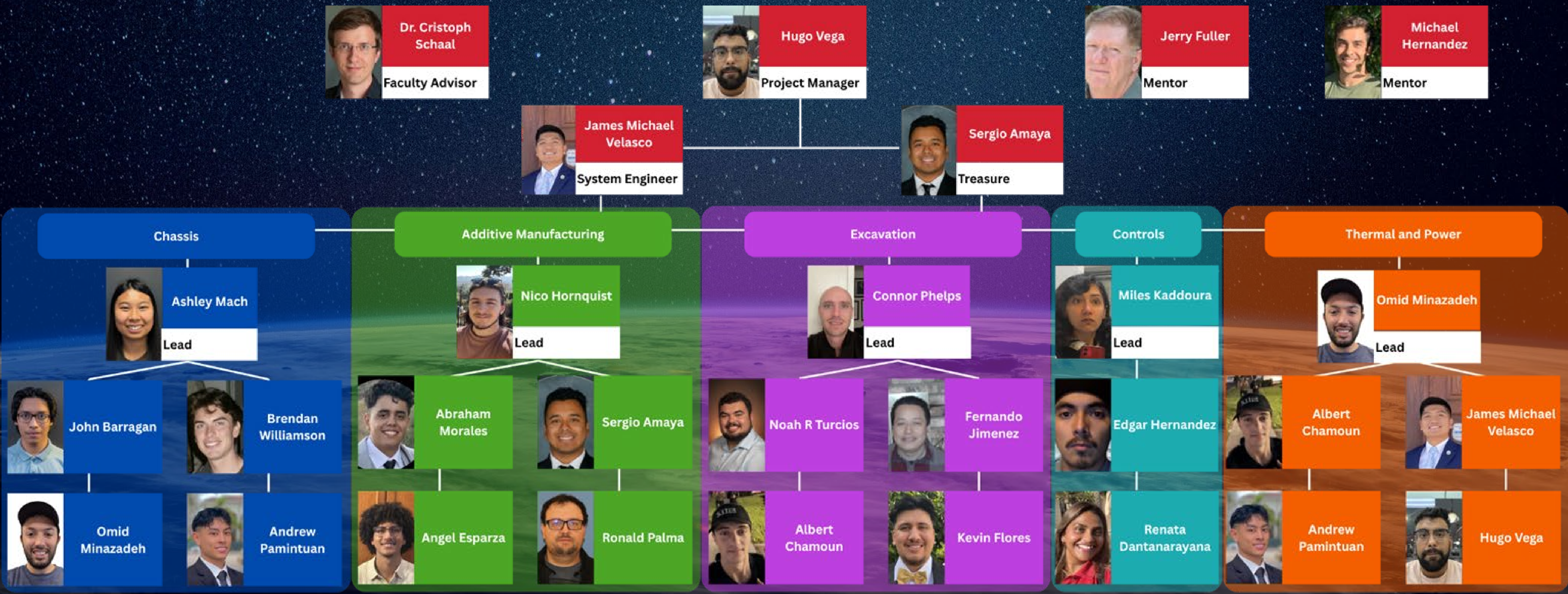
Mentors: Michael Hernandez & Jerry Fuller

Executive Summary

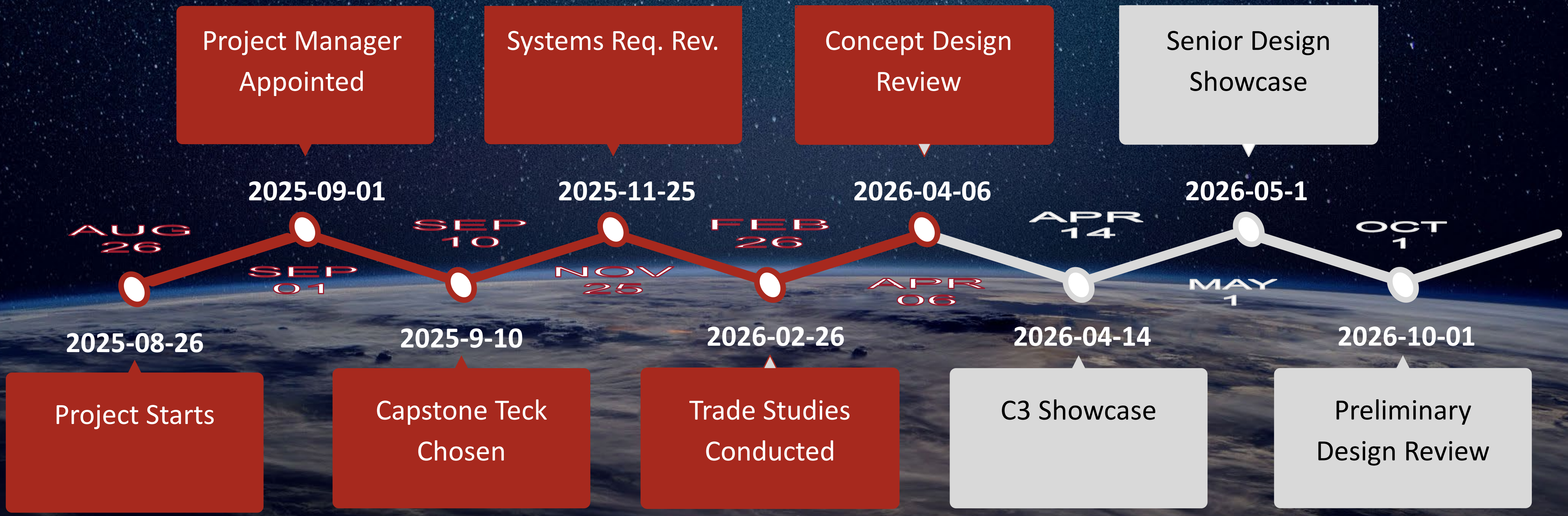
- The CSUN ISAM R&D team has developed a rover that supports the construction of permanent lunar infrastructure through additive manufacturing processes using in-Situ resources
- The system will excavate regolith using a drum bucket and sieve, and dispense the processed regolith into layers. Using SLS printing, a 150 W diode laser will sinter on the lunar surface for usable construction bricks.
- The rover demonstrates the integration of the chassis with excavation, additive manufacturing, power and control systems to work together with the Griffin Lunar Lander to support our mission.



Team Overview



Program Management Milestones

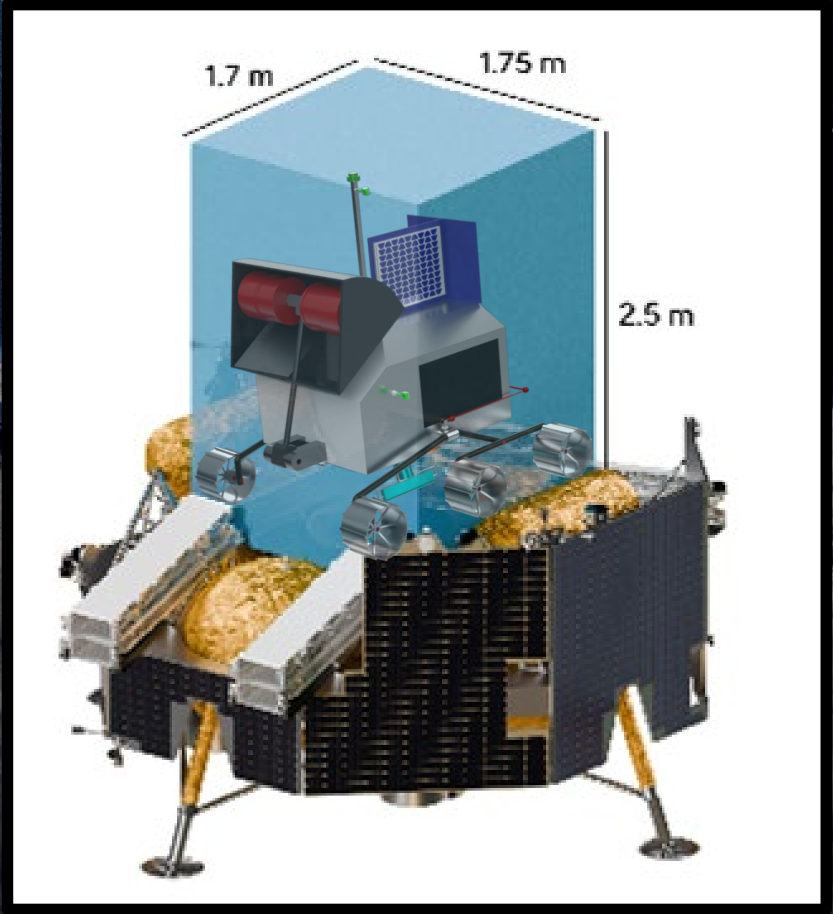


Griffin Lunar Lander

Constraints

- Mass Limit: 200 kg
- Volume Allocations: 1.7m x 1.75m x 2.5m
- Communications: 5G relay at 60 Mbps with links to Earth
- Power Available for Use: 5kWe solar power; inductive charger for wireless charging; battery for 80W (70W for lander systems + 10W for construction systems) over 100hr to survive lunar night (8kWh)
- Autonomy: Limited remote commands, high onboard autonomy
- Mission Lifecycle: Design must account for the entire mission lifecycle, beginning from launch and up to surface operations

Payload Volume Envelope (Griffin Lander)



Considered Concepts

Compactor

- Uses vibration to compact regolith so that landing pads and shelters can be built upon stabilized ground
- May or may not use sprayed on binders to stabilize the ground

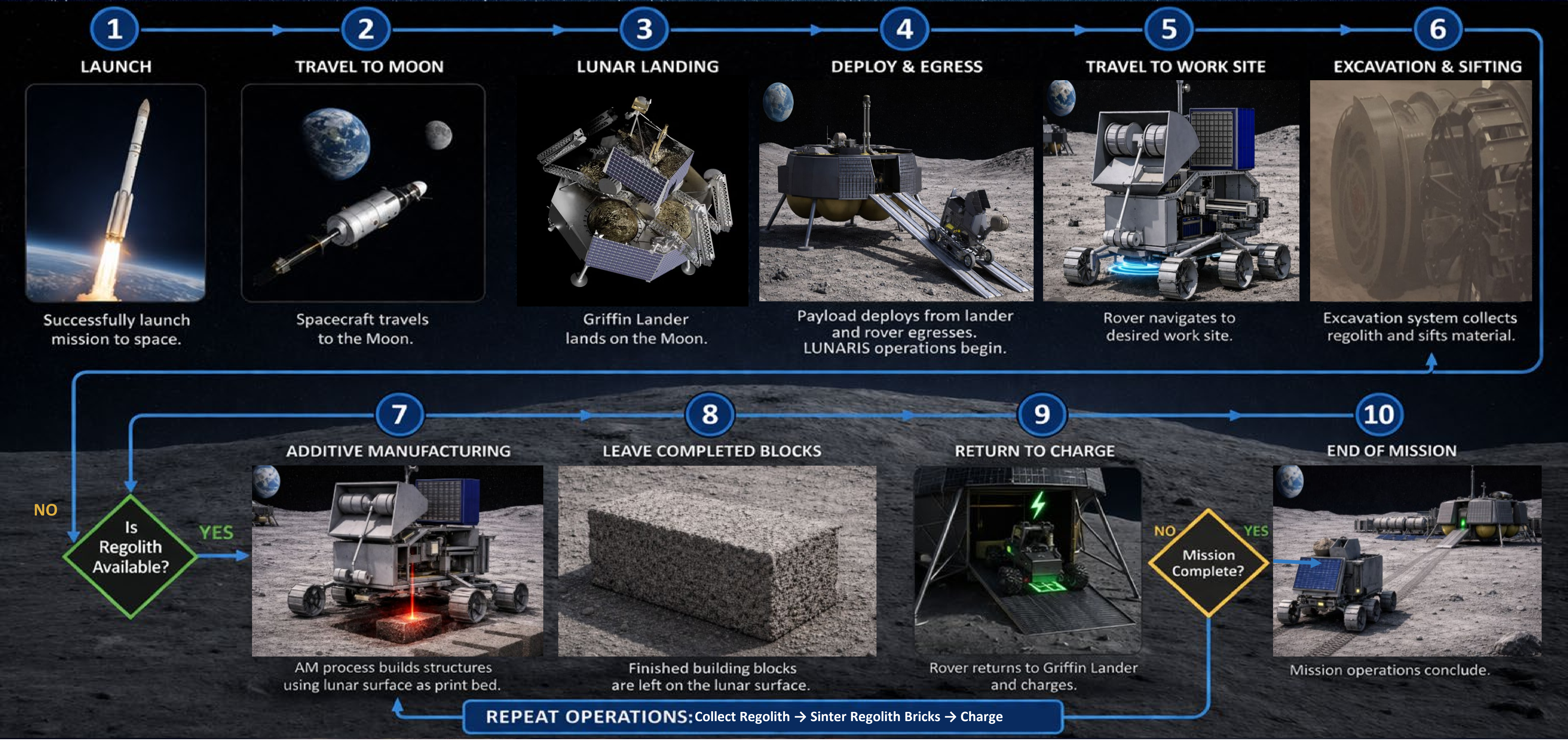
Space Truck

- Can navigate the rough terrain and transport materials and equipment
- Aids in material gathering for Moon base storage
- Potential use for mining operations

Origami Pop-up Tent

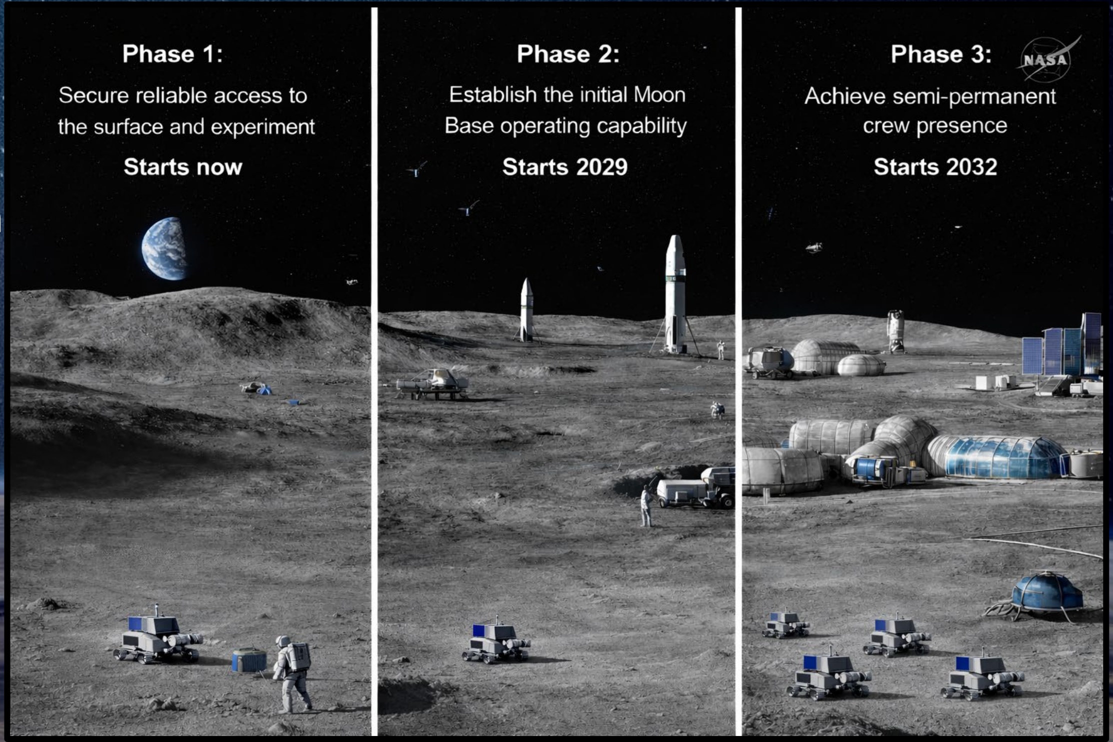
- Ease of assembly can help accelerate NASA's Moon-to-Mars missions by supporting initial missions on the Moon.
- Ability to maximize available payload space by packing folded up structures and setting up when on the Moon

Storyboard; ConOps



Impact of Design

L.U.N.A.R.I.S rover enables infrastructure in Phases I-III



Lunar Development Phases (Nasa Architecture)

Phase I: Build, Test, Learn

- Increased lunar activity through robotic missions and tech demo
- Autonomous regolith excavation and laser sintering on the surface

Phase II: Establish Early Infrastructure

- Semi-habitable infrastructure and regular logistics
- System will support early infrastructure such as landing pads, roads, and walkways

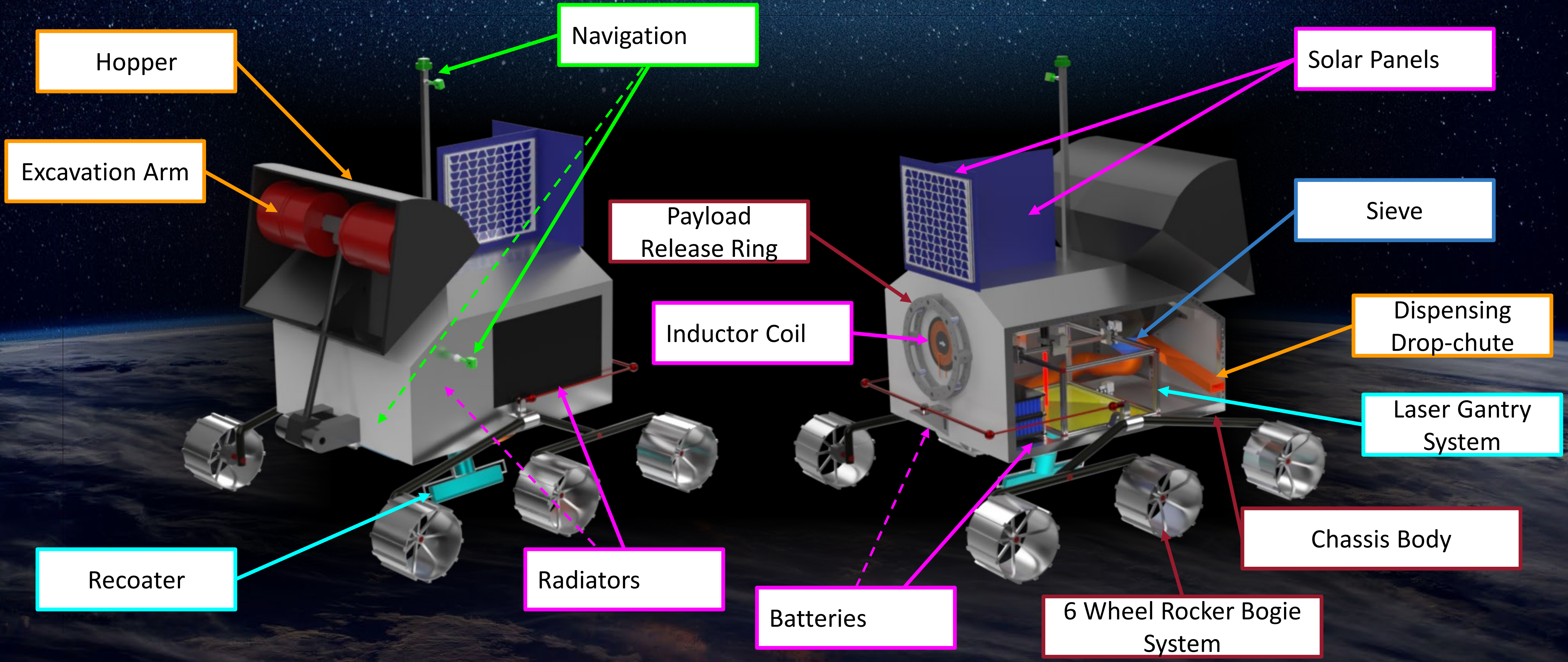
Phase III: Enable Long-Duration Human Presence

- NASA will transition to long-duration missions and a permanent lunar base
- Enables NASA’s Moon-to-Mars architecture by validating ISRU, autonomy, and infrastructure systems required for Mars missions

System Impact

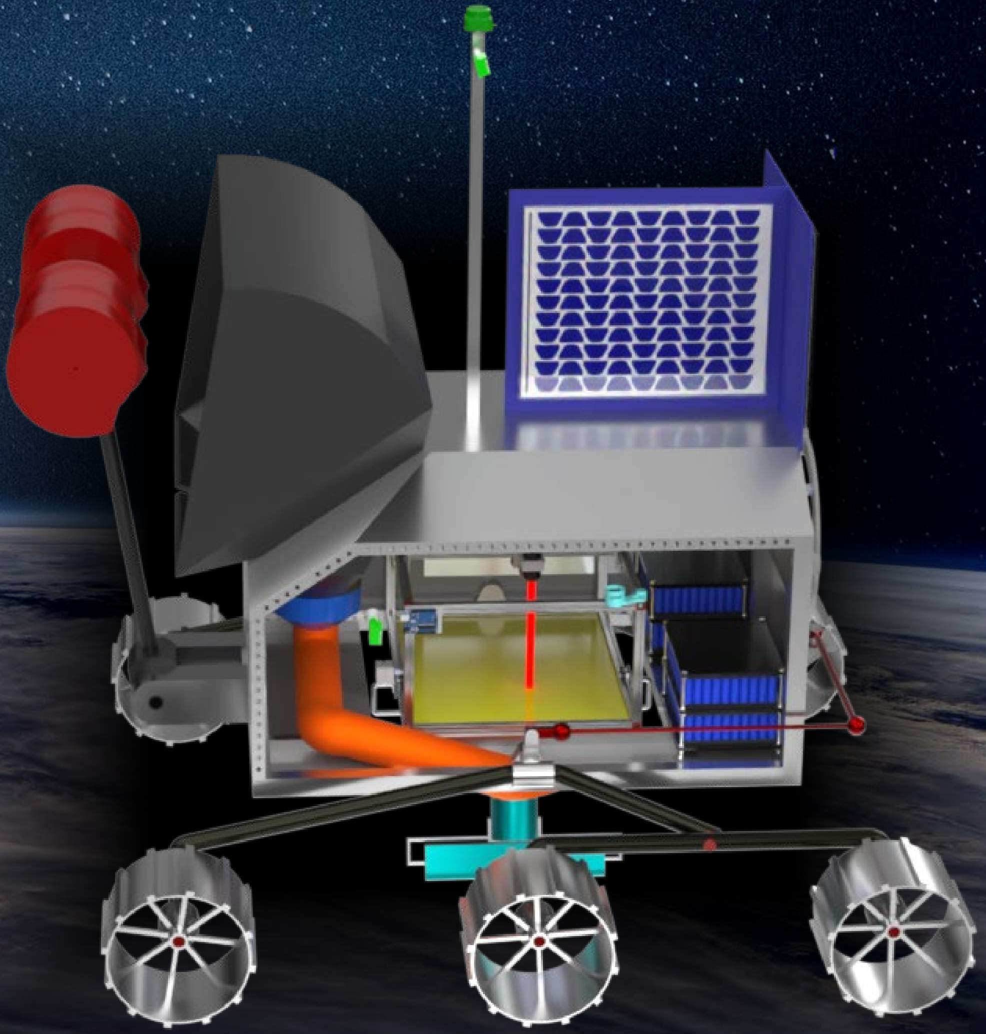
- Supports Moon-to-Mars Architecture through ISRU-based construction
- Reduces launch mass and mission cost
- Scalable for sustained lunar presence

System Overview

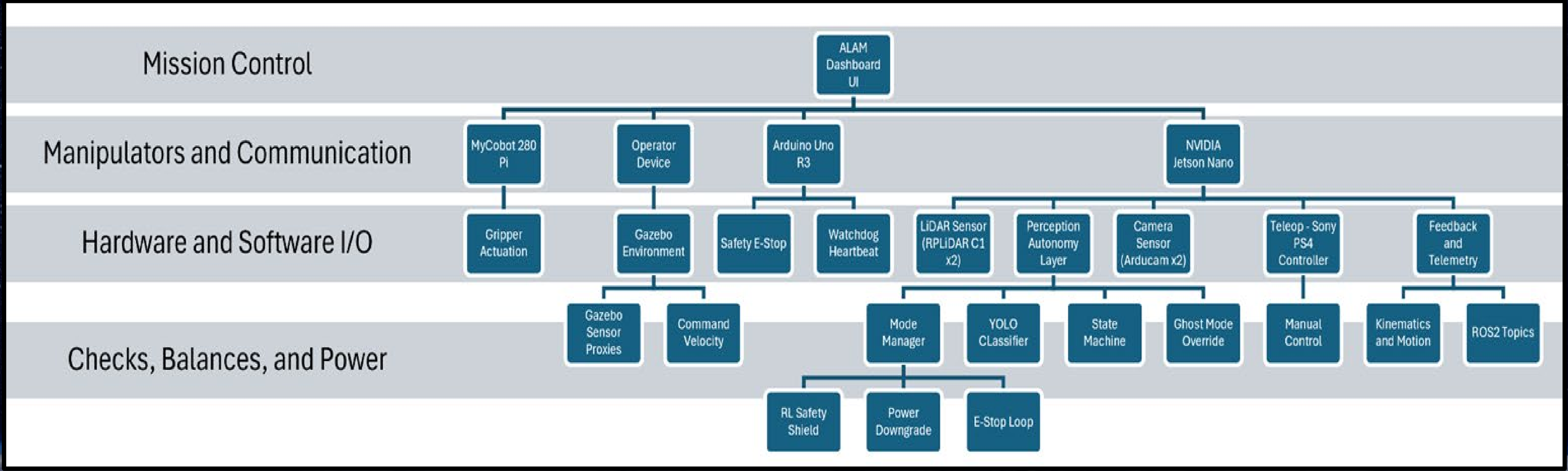


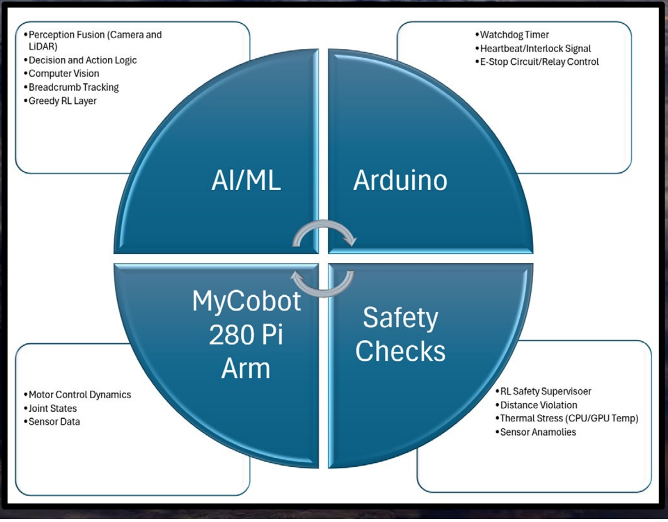
Spec chart of Rover

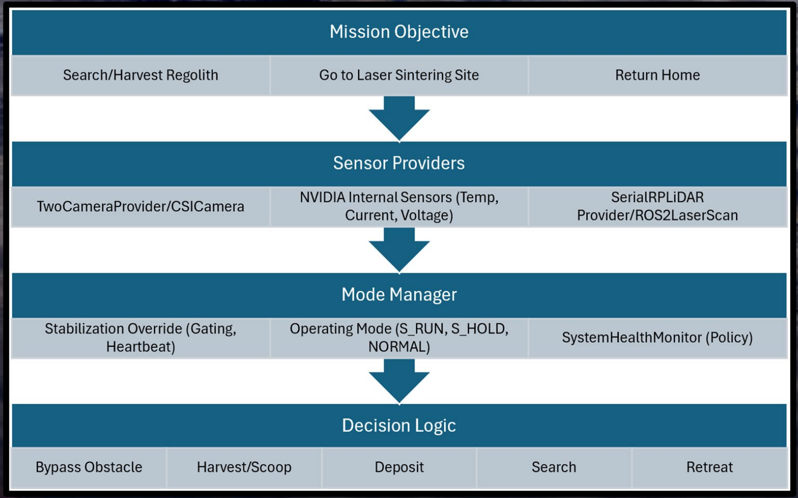
Specification	Value
Mass of System CAD	196.71 kg
System Volume	1.696 x 1.577 x 2.008 m
Average Rover Speed	0.322m/sec
Solar Power Generation	250 W
Battery Charge Time	18.5 Hours
Nighttime Power Consumption	12 W
Daytime Power Consumption	545 W
Print Time (Full Infill)	34 min per layer
Regolith Collection Rate	100 g/ min
Total Regolith Storage	25 Kg



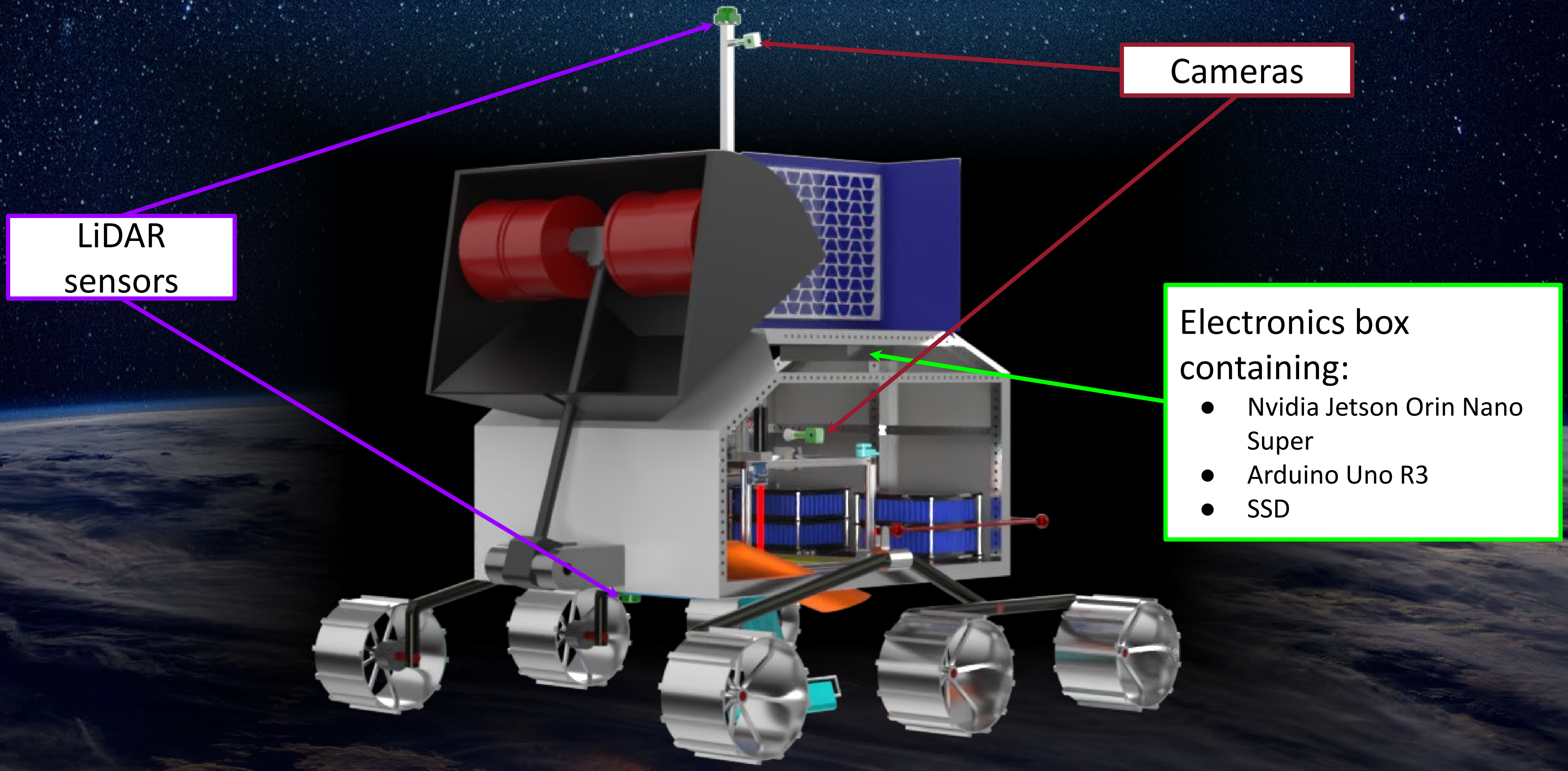
Software Architecture - CS



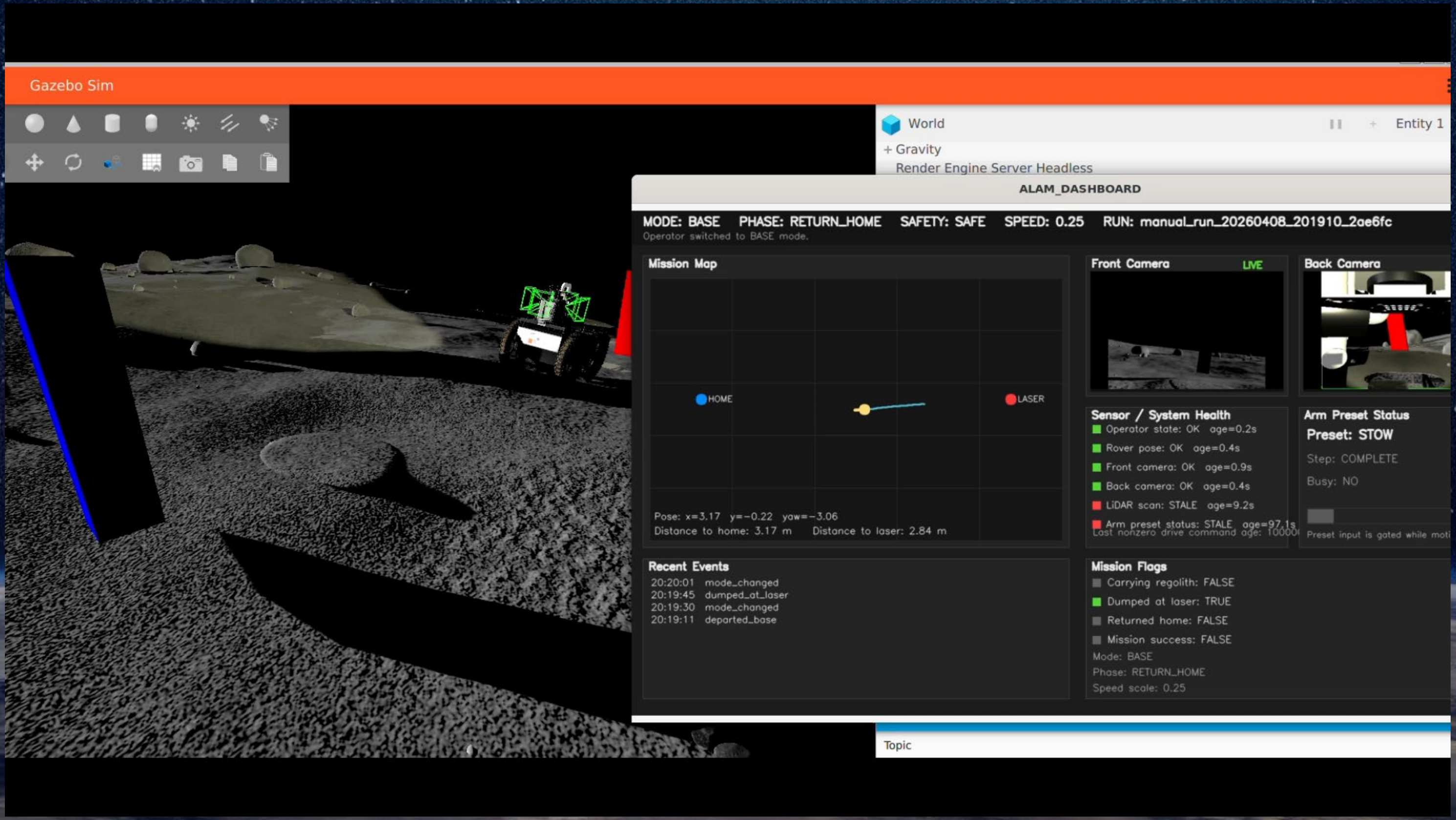




System Controls Overview



Gazebo Moon Simulation with Sensor Proxies - CS

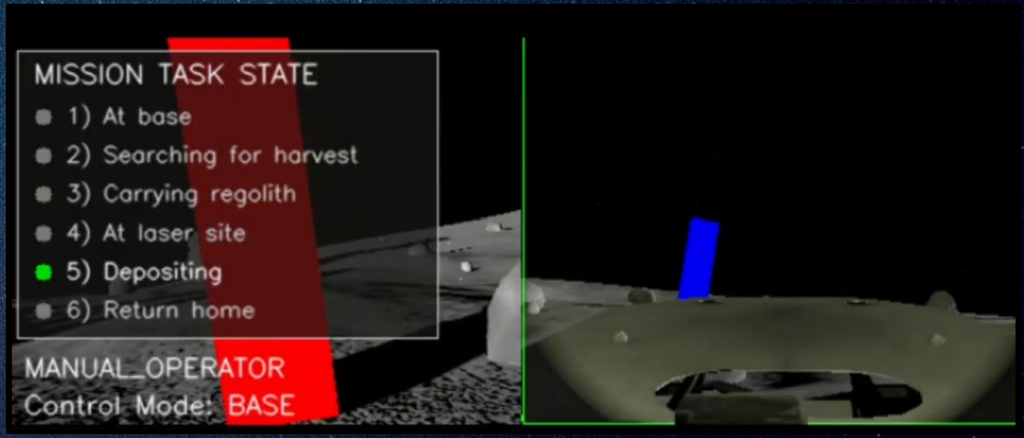



```
=== ALAM Operator Menu ===
1) Manual Operator
2) Autonomous Driver (stub)
3) Exit
Select option: 1
[manual] controller backend = pygame | PS4 connected: Sony Interactive Entertainment Wireless Controller
[manual] drive backend = ros_twist -> topic /cmd_vel
[manual] arm backend = ros_string -> topic /arm_preset_cmd

Entering Manual Operator. Press Ctrl+C to return to the menu.
[event] 2026-04-08T20:44:50 operator_session_started :: Manual operator app entered.
[dashboard] run=manual_run_20260408_204450_969994 mode=BASE phase=AT_BASE safe=SAFE speed_scale=0.25 carry=False dumped=False home=False success=False
[drive] linear=0.0000 angular=0.0000 speed_scale=0.25
```

Moon Simulation - Trials for Rover Body with Arm

Arm Only - Live Regolith Classification



Rover Only - Moon Environment View

- Accuracy: 0.952
- Average Time First Harvest Zone: 7.286 sec
- Average Time First Object: 8.53 sec
- Average Time First Human: 14.6 sec

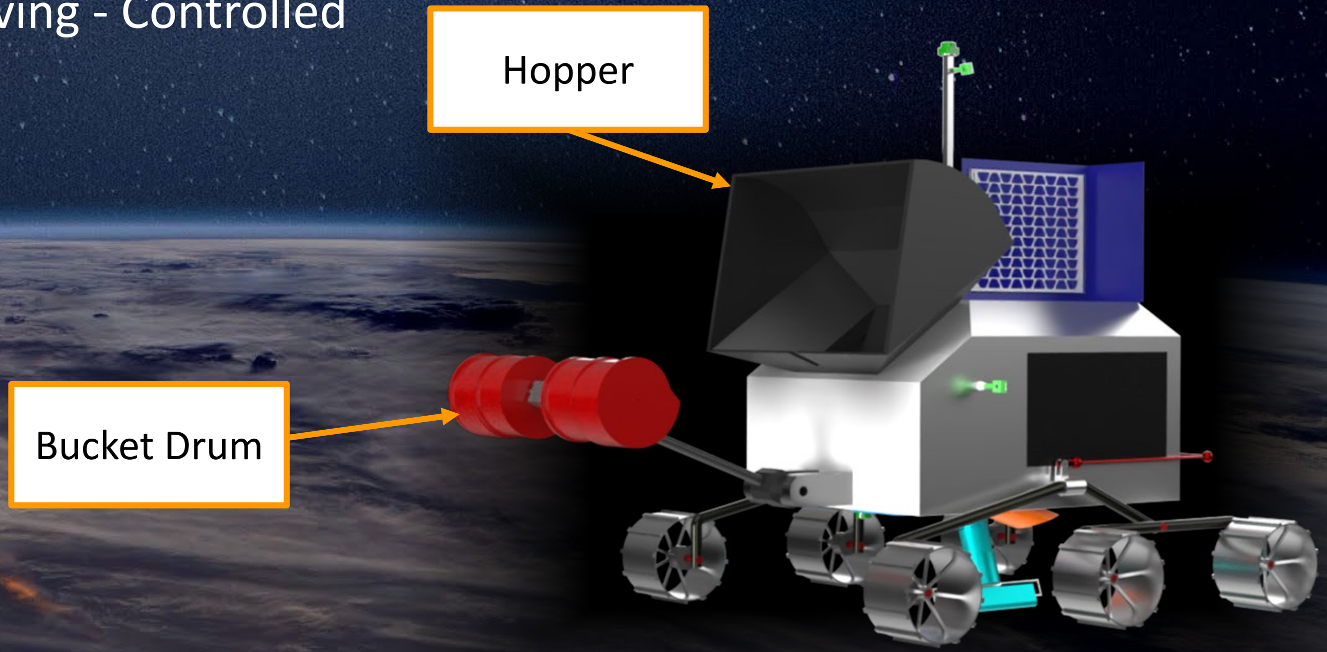
Excavation Summary

Subsystem Purpose:

- Excavate, transport and condition lunar regolith for ISRU.
- Designed for a low-gravity, highly abrasive lunar environment.
- Continuous material flow: Excavation - Sieving - Controlled Dispensing
- Operational time: 60 minutes

Drum Geometry & Capacity

- Drum diameter: 0.318 m
- Internal volume: 0.0165 m^3 (16.5 L)
- Regolith capacity (full drum): 25 kg
- Assumed bulk density: 1500 kg/m^3
- Operational Speed: 30 RPM
- Operational time: 30 minutes



Excavation Summary

Challenge: Lunar regolith contains particles from sub-micron dust to coarse rocks

Mechanical Vibration

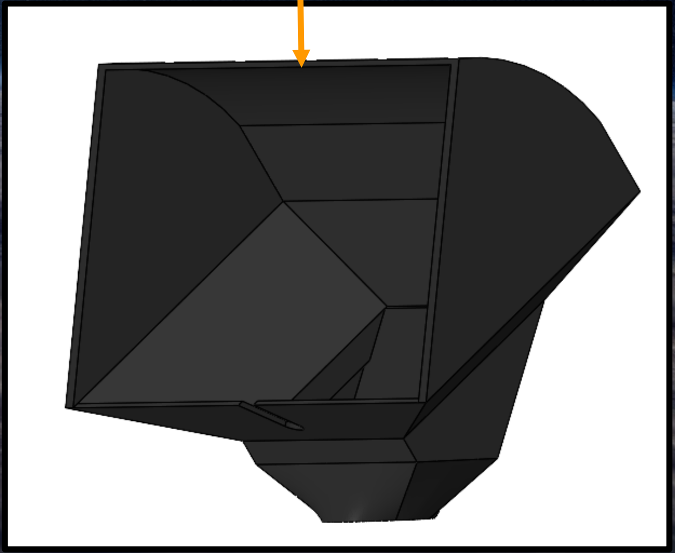
Operational time: 30 min

Mesh size(s): Mesh 1: 80 Micrometers

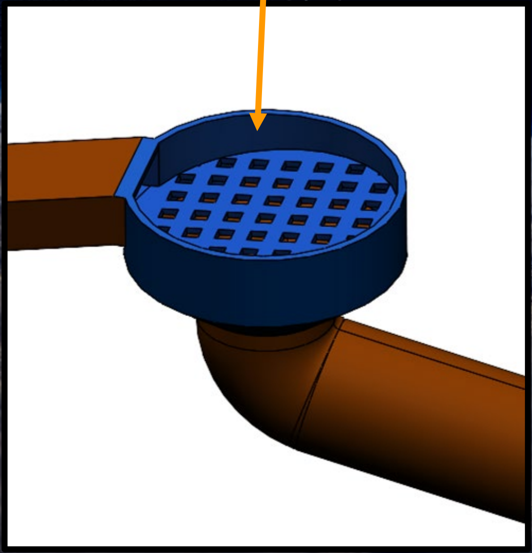
Mesh 2: 20 Micrometers

- Typical lunar Soil Range: 40-800 micrometers
- Median Lunar Soil Size: 40-130 micrometers
- Fine Fraction below 20 micrometers: 10-20%
- Target Output: 20-80 micrometers

Hopper with Mesh 1



Sieve with Mesh 2

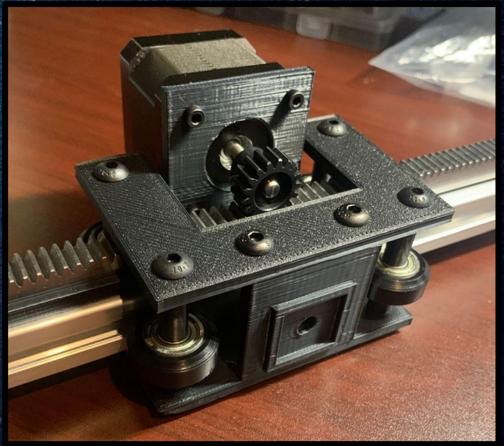


Additive Manufacturing Summary

Key Design Choices

Rack and Pinion vs. Belt and Pulley

- Given that there is no way to service the rover, the goal was to design a robust and reliable drive system for x-axis and y-axis of the gantry
- Using a Rack and Pinion design avoids the stretching associated with belts, providing a service life of 10-15 years, and maintains a dimensional accuracy within ±1.0-1.5mm


Rack and Pinion Drive System

40W Laser vs. 150W Laser

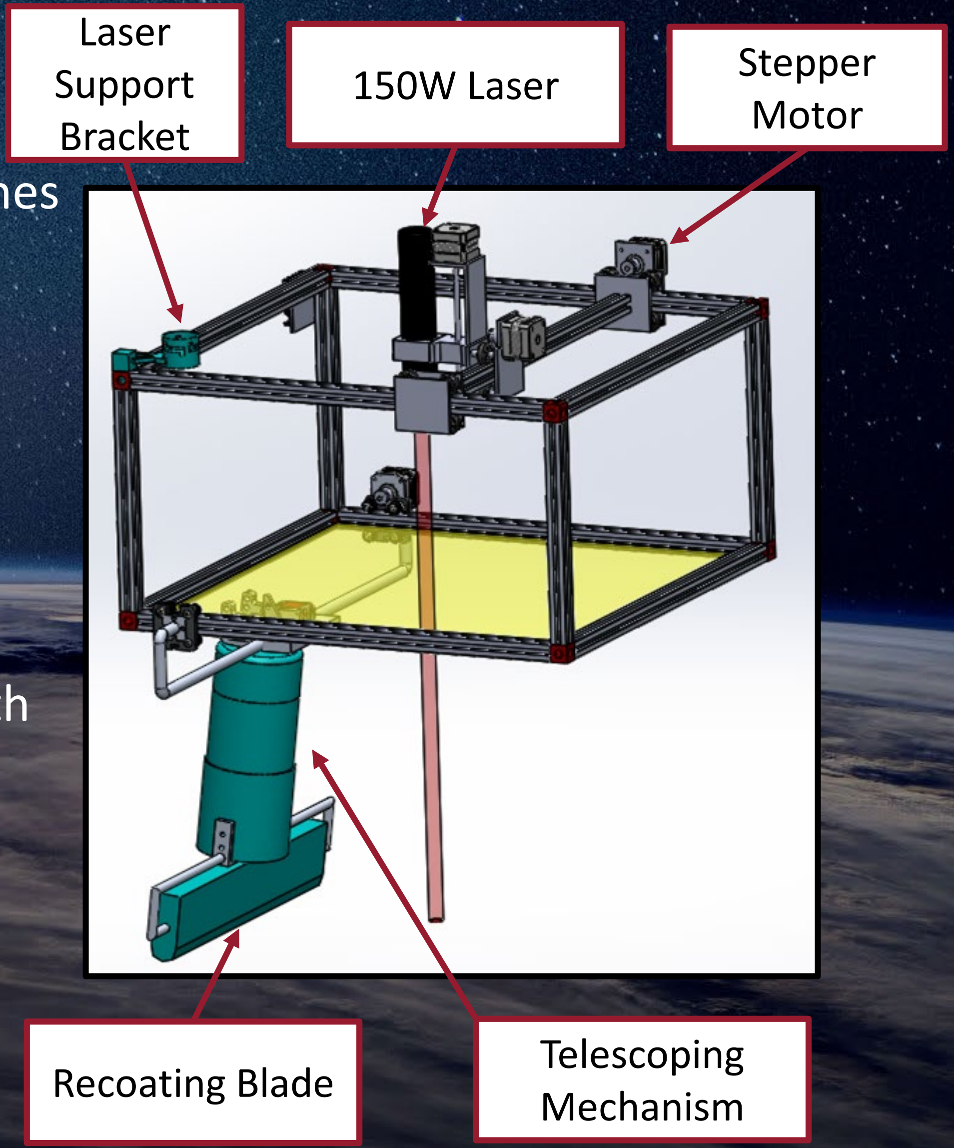
- Testing proved that a 40W laser was incapable of sintering regolith simulant, whereas a 150W laser with a 10.6 μm wavelength proved to be sufficient
- As a result, opting for a 150W diode laser proved to be the ideal choice in reaching a minimum of 10% efficiency that can allow for a sintering time of 20 minutes per layer


Sintering Achieved with 150W Laser

Additive Manufacturing Summary

3-Axis Gantry
Located inside the rover, gantry positions a laser beam that reaches the ground through a germanium glass window that preserves optical power
Capabilities:
- Supports a maximum brick geometry of 400mm x 400mm x 100mm
- Allows laser to travel at a rate of 500 mm/min
- Can be configured using G-code

Recoating Device
Located outside of the rover, the recoater will spread new regolith between sintering passes
Capabilities:
- Blade ensures 0.2 mm layer height is achieved consistency
- Assembly folds up towards the rover for traversing the moon
- Works in conjunction with the program written for the gantry



Chassis Summary

Key Design Choices

4 Wheeled Rover vs 6 Wheel Rocker Suspension Rover

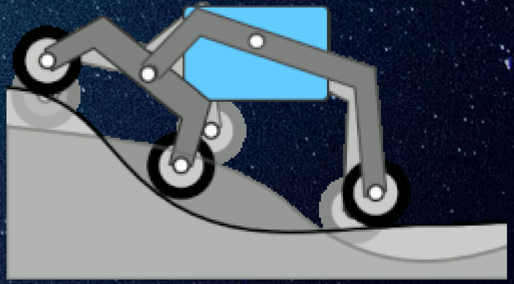
- 4 wheeled system has obstacle capability of 30-40% wheel diameter with TRL: ~4-6
- A 6 wheeled rover has higher TRL of 8-9 and obstacle capability of 70-80% wheel diameter

Independent Wheel Drive

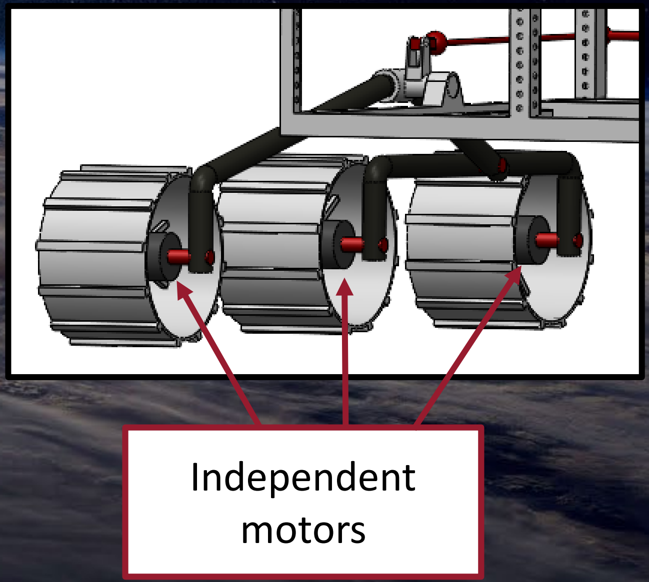
- Independent motors per wheel provide redundancy
- Enables precise control and zero turning radius for accurate positioning during sintering
- Eliminates dependence on a single drivetrain, reducing single-point failures
- Improves traction control across uneven terrain

Central vs Rear Mounted Differential Bar

- CM: 2 points of connection to wheels, but obstructs the available internal space
- RM: 3 points of connection, differential bar aids in self leveling the legs



Rocker-bogie system



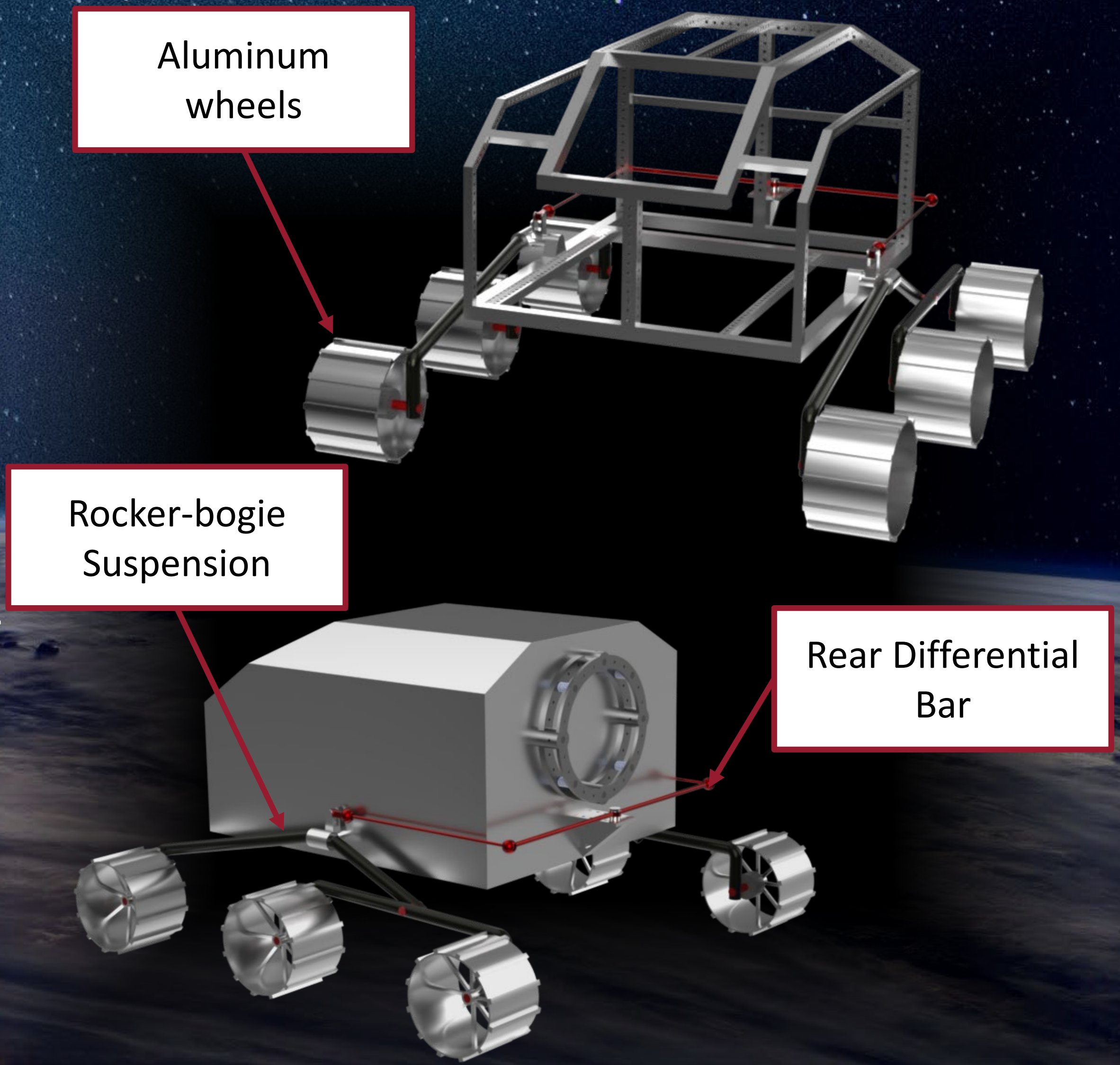
Chassis Summary

6 wheel Rocker Bogie Suspension
Maintains continuous wheel-ground contact and distributes load across uneven lunar terrain using a passive linkage system

Capabilities:
- Traverses obstacles up to 0.3 meters
- Maintains stability on uneven terrain without active suspension
- Eliminates needs for actuators, reducing complexity

Rear Differential Joint
Passively balances motion between left and right rocker arms to maintain stability during traversal

Capabilities:
- Allows independent pitch motion between left and right sides
- Prevents wheel lift-off on uneven terrain
- Distributed loads evenly across all wheels



Thermal Summary

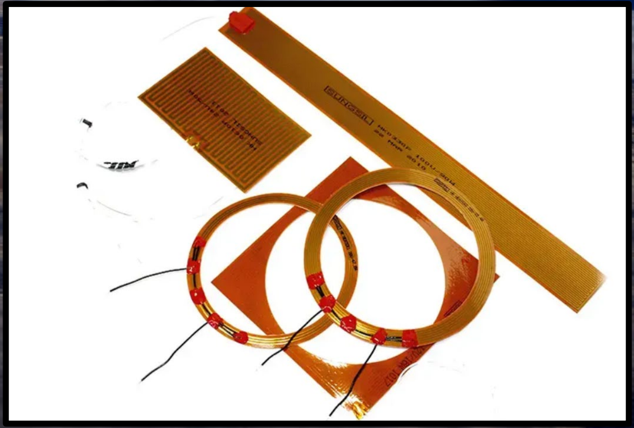
Passive Thermal Control

- MLI (Multi-Layer Insulation) reduces heat loss and protect sensitive components
- Radiator panels reject excess heat into space
- Loop heat pipes transfer heat from electronics and battery to radiators
- Passive thermal design minimizes power use and improves reliability

Multi-Layer Insulation

Active Thermal Control

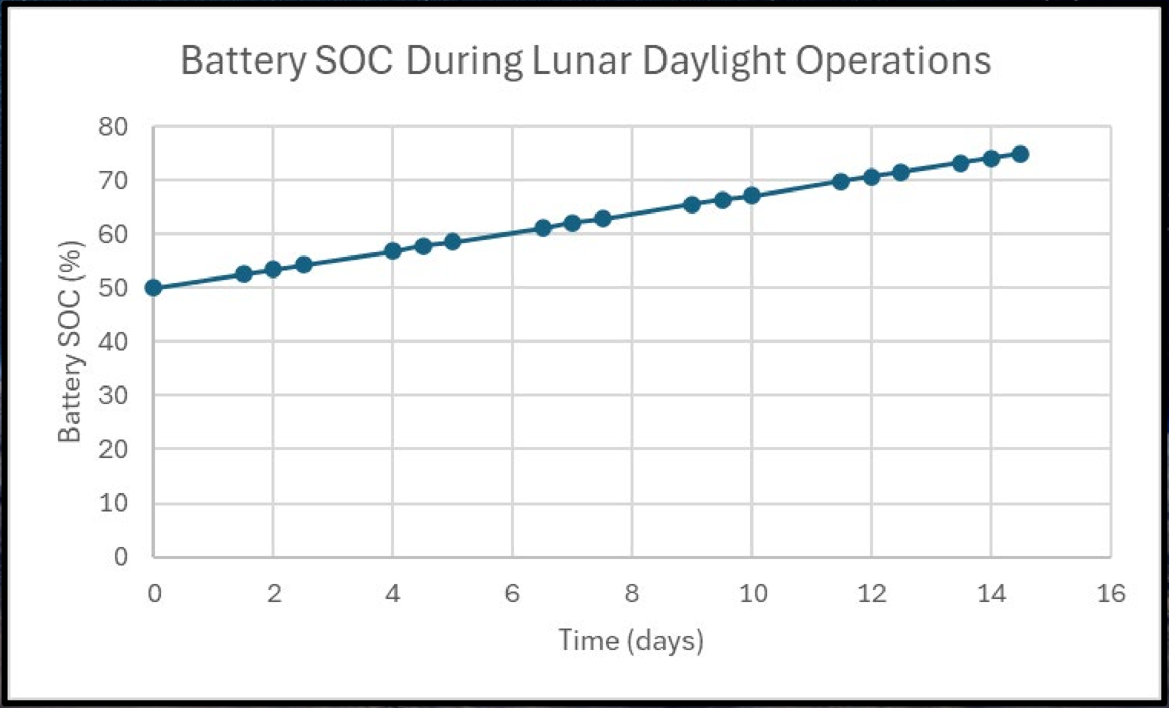
- Kapton resistive heaters prevent freezing during lunar night
- Heaters maintain battery and avionics within operating temperature range
- Thermal control supports approximately 348 hr lunar night survival
- Active heating is limited to essential survival loads only



Kapton heaters

Power Summary

- Total power requirement in each rover mode must be achieved and may not surpass the total available power supplied by a 6.6 kwH battery, solar panels, and induction charging
- The battery state of charge rises during the 14.5 Earth day cycle, hence that the rover has enough energy from the sun to perform its functions
- Battery charge level does not fall below a critically low value (30%) [2] according to the chart above, indicating the presence of sufficient energy reserves in the battery
- The daytime energy strategy is feasible since the battery charge is not depleted faster than its recovery



Launch Considerations: Static Loads

Chassis Structural Analysis (FEA) Analysis Methodology & Setup

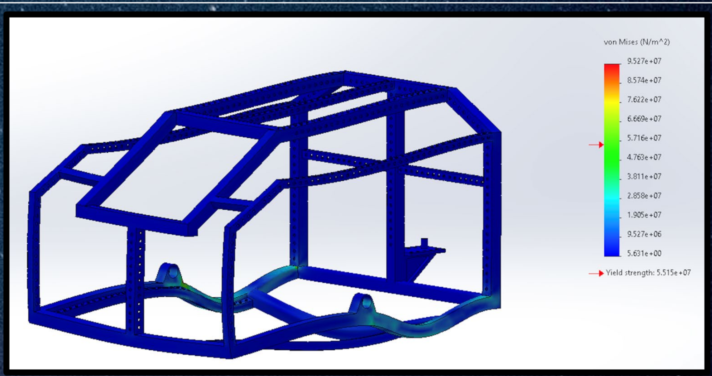
- Material: Aluminum 6061
- Loading Conditions: 200 kg worst-case distributed load at subsystem mounts
- Software: SolidWorks
- Boundary Constraints: Fixed wheel interfaces

Results

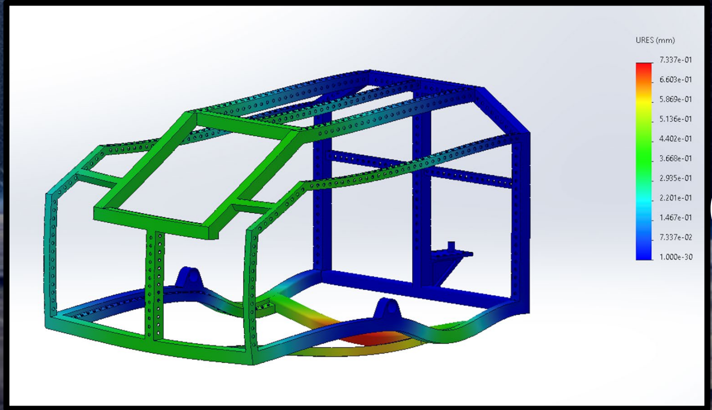
- Max Displacement: 0.73 mm
- Peak stress localized at suspension mounts
- Factor of Safety (FoS):
  - Global: > 1.5 for majority of structure
  - Local: 1.06 at sharp geometric transitions

Takeaways

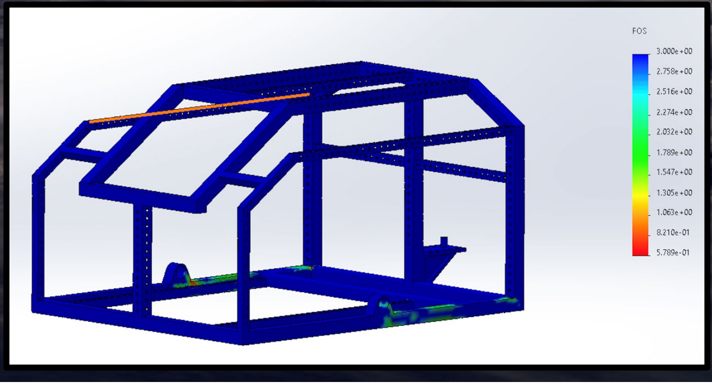
- Design Refinement: Implement fillets to mitigate local stress
- Target: Refinements will bring minimum FoS to 1.5 without adding mass



(a) Stress



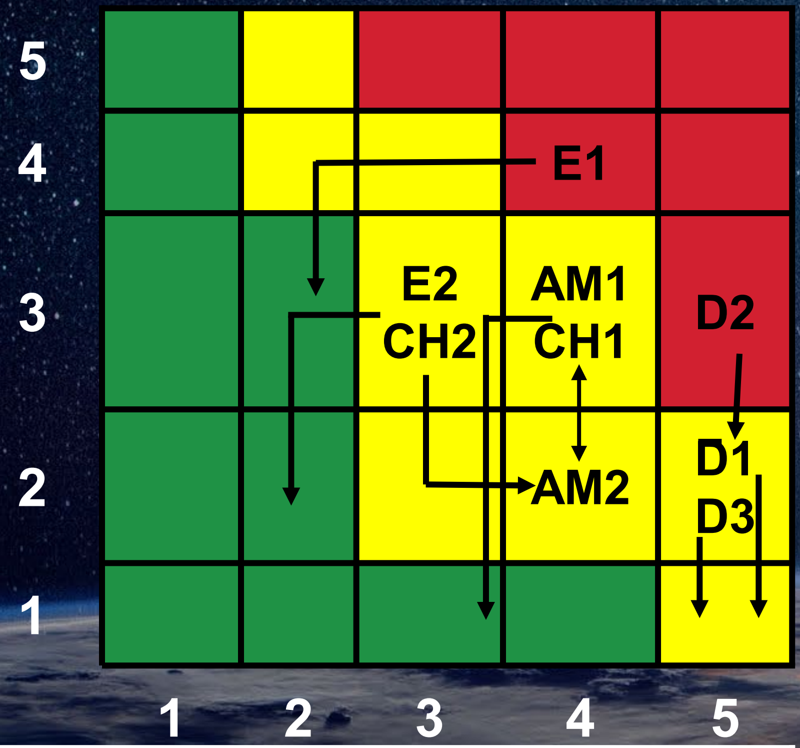
(b) Displacement



(c) FoS

Risks

Likelihood of Failure
Very High 51-100% (5)
High 26-50% (4)
Medium 13-25% (3)
Low 6-12% (2)
Very Low 0.5% (1)



Consequence of Failure	
Catastrophic (5)	Results in total mission failure
Critical (4)	Failure to satisfy several mission requirements
Moderate (3)	Failure to satisfy a mission requirement
Minor (2)	Disruption to mission timelines
Negligible (1)	Minimal to no impact on the mission outcome

System Risks		Mitigation Strategy
D1	Release Mechanism	Use a redundant release mechanisms and test before launch
D2	Battery Depletion	Implement minimum battery threshold for rover to return to charge
D3	Mass/Power Exceeded	Track mass and power budgets
E1	Regolith Accumulation	Use of EDS mechanisms in prone areas or seal components/covers
E2	Excavation Jam	Use clearance margins and reverse motors to clear jams
AM1	Thermal Control	Use heaters and radiators to keep components in safe temp zone
AM2	Laser/Recoater Failure	Monitor temperature with sensors, reduce weight, and include automatic shutdown
CH1	Mobility Failure	Use redundant drive capability to maintain movement if something fails
CH2	Navigation	Use several sensors around the rover to improve obstacle detection reliability

Manufacturing & Testing

Chassis Center of Gravity

- The center of gravity for the entire system needs to remain stable regardless of:
  - Rover Angle of Attack
  - Bucket Drum Fill Ratio
  - Arm Position

Electrodynamic Dust Shields (EDS)

- Mitigates regolith build up
- Less wear and tear on vital systems
  - Laser Lens
  - Gantry System
  - Rack & Pinion System

Rover Assembly

- Ensuring protection & security for all components attached to the rover
- Maintaining component stability during excavation & exploration
- Guaranteeing rover will survive launch and unloading
- Collapsed system must fit in required cargo area

Technological Gap Assessment

Regolith Sifting

- Eject unwanted larger particles through vibrations
- Separate regolith with desired particle size of 80µm, required for successful sintering
- Resistance to constant regolith wear & tear

Bucket Drum Excavation System

- Mitigate regolith kickup on system during operation
- Controlled dumping process into hopper
- Refill hopper system with minimal power used

Lunar Surface Printing

- Requires further testing of laser printing on regolith in vacuum conditions
- Expel enough heat through radiators
- Testing of leveling capability on uneven surface

Biggest Challenges

Mass Constraints (200 kg Limit)

- Optimizing subsystem performance (Chassis, Additive, Excavation, Thermal, Hardware) while meeting strict mass limitations
- Required continuous trade offs between efficiency, strength, and functionality

Power Constraints in Lunar Environment

- Managing energy demands for a complex, multi-system architecture
- Ensuring functionality during lunar day and survivability through lunar night

Concept Development & Team Alignment

- Converging on a single mission concept across an 18 member team with diverse ideas
- Evaluating solutions based on novelty, feasibility, and innovation

Innovative Concepts Used

In-Situ Regolith Additive Manufacturing
- Converts lunar regolith into structural bricks
- Bricks printed directly on the lunar surface

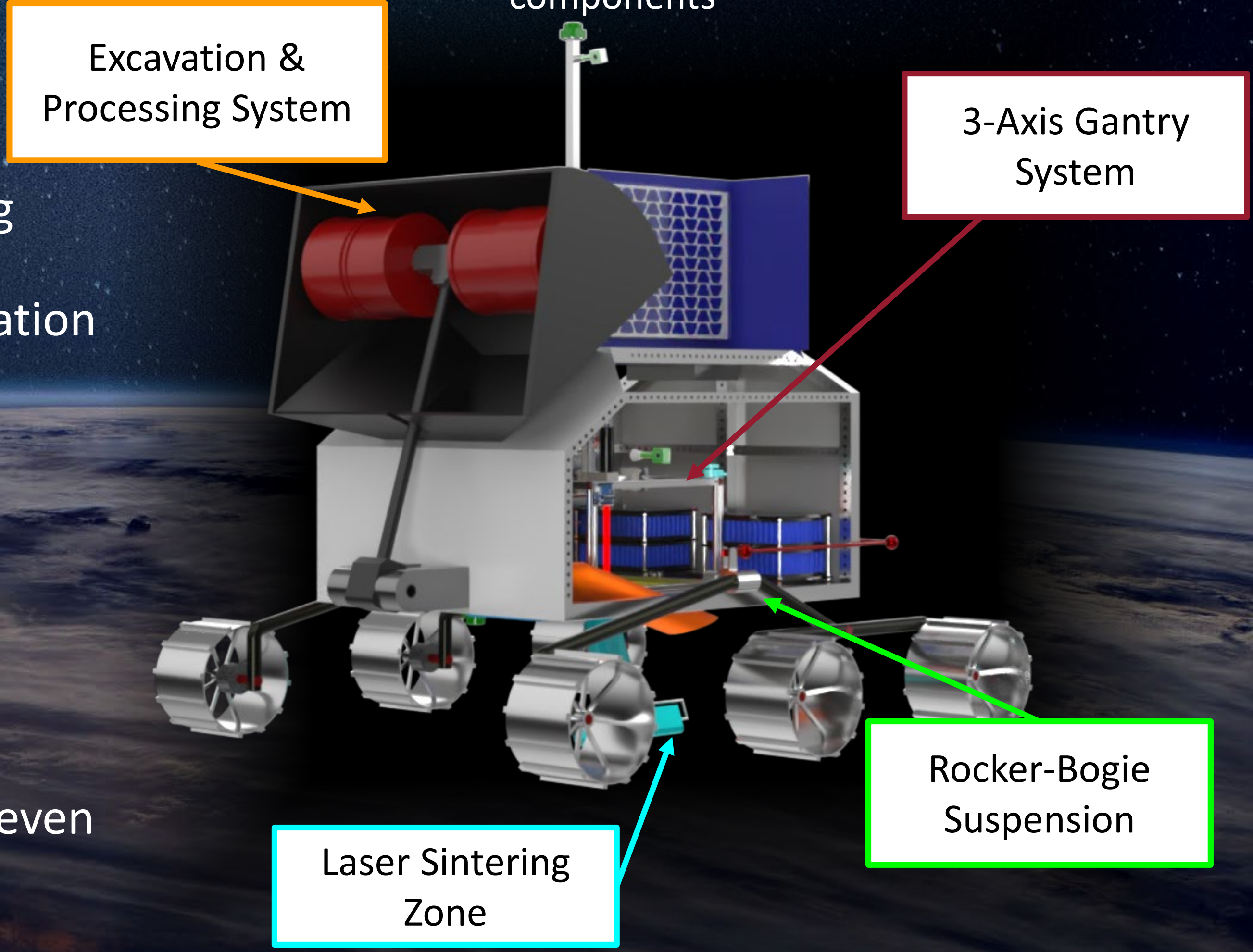
Integrated Excavation-Manufacturing Architecture
- Single system: excavation + processing + printing

Mobile Manufacturing Platform
- Enables construction directly at the site of operation
- Removes need for transport between systems

Precision Internal Gantry System
- Rack and pinion driven 3-axis system
- Accuracy and reliability in an unserviceable environment

Rocker-Bogie Suspension for Operational Stability
- Passive leveling during traversal and printing operations
- Ensures consistent manufacturing quality on uneven terrain

*Note: Body panels hidden to display interior components



Path to Preliminary Design Review (PDR)

Phase A (2025) Concept Development	Phase B (2026) Pre-PDR Validation	Phase C (2027) Preliminary Design Review	Phase D (2028) Design Refinements
Completed	WIP	Pending	Pending
Define mission requirements and constraints	Full system CAD model	CAD and subsystem integration	Build and test prototype components
Research excavation and regolith handling methods	Integrate all subsystems	Validate requirements	Verify functionality and durability
Identify key subsystems and select baseline concept	Perform initial analysis and select materials	Update analysis and performance estimates	Finalize integration and documentation

LEGEND: Completed WIP Pending

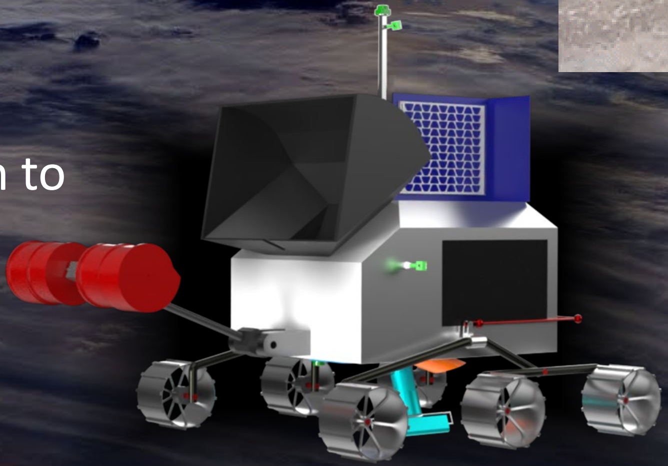
Conclusion

CSUN & ISAM's Project LUNARIS demonstrates how a lunar regolith brick could become the stepping stone into being vital for lunar construction

LUNARIS showcases integration between systems:

- Control System
- 6 Wheel Drivetrain
- Excavation Bucket Drum
- Sieve
- Recoater
- Laser System

Using in-Situ materials that can become the foundation to any structure NASA can construct in any future civil engineering projects on the Moon.



Questions?

References

[1] NVIDIA, n.d., "Jetson Orin Nano Series, Jetson Orin NX Series and Jetson AGX Orin Series," NVIDIA Jetson Linux Developer Guide, NVIDIA, accessed Apr. 7, 2026, https://docs.nvidia.com/jetson/archives/r36.4.4/DeveloperGuide/SD/PlatformPowerAndPerformance/JetsonOrinNanoSeriesJetsonOrinNxSeriesAndJetsonAgxOrinSeries.html

[2] Battery University, n.d., "BU-802c: How Low Can a Battery Be Discharged?," Battery University, Cadex Electronics Inc., accessed Apr. 7, 2026, https://www.batteryuniversity.com/article/bu-802c-how-low-can-a-battery-be-discharged/

[3] Astrobotic Technology, 2012, "Astrobotic Unveils Lunar Polar Rover," Astrobotic Technology, Oct. 8, accessed Apr. 7, 2026, https://www.astrobotic.com/astrobotic-unveils-lunar-polar-rover/

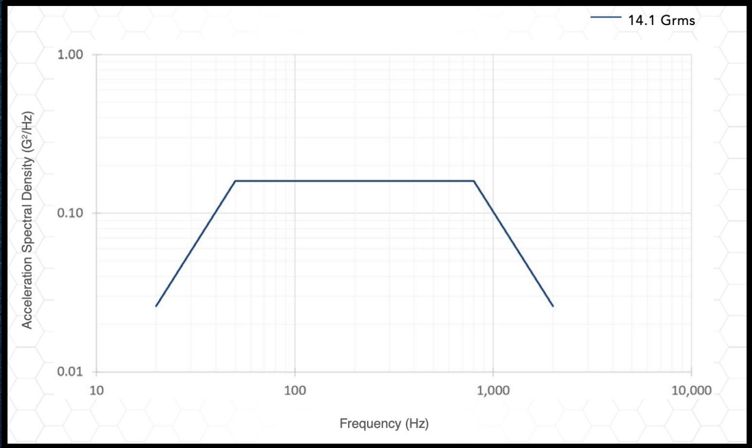
[4] National Aeronautics & Space Administration, 2012, "Regolith Advanced Surface Systems Operations Robot (RASSOR)", National Aeronautics & Space Administration, accessed Apr. 8, 2026, https://ntrs.nasa.gov/api/citations/20130008972/downloads/20130008972.pdf

[5] National Aeronautics & Space Administration, "Design of an Excavation Robot: Regolith Advanced Surface Systems Operations Robot (RASSOR) 2.0", National Aeronautics & Space Administration, accessed Apr. 8, 2026, https://ntrs.nasa.gov/api/citations/20210011366/downloads/ASCE%202016%20RASSOR%202%20Final%20%206_8_2016.pdf

Launch Considerations: Vibration

Launch Setup:
- Astrobotic Griffin lander payload configuration
- Payload Release Ring as primary interface
- Bonded assembly for structural simplification

Mass Modeling:
- Total Mass: 200 kg
- Modeled CAD: 20.13 kg
- Remote mass: 179.87 kg
- Distributed (front, center, rear) for realistic inertia

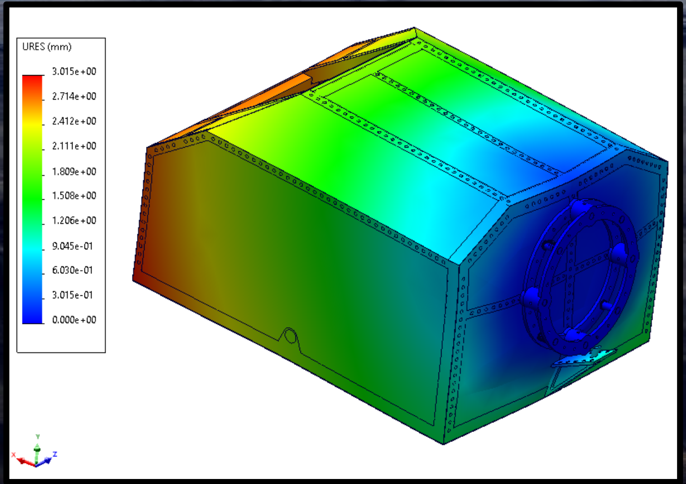


Astrobotic Launch PSD Profile

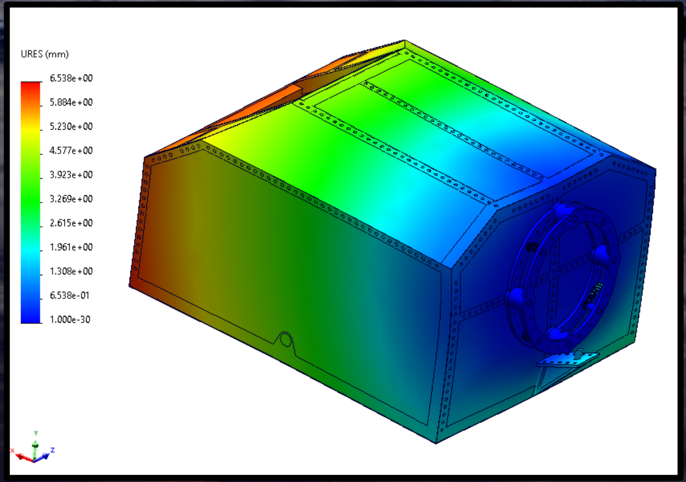
Vibration Analysis Input:
- PSD from Astrobotic payload guide
- Peak value used: 0.16 g^2/Hz
- Applied as base excitation in X, Y, Z

Deformation concentrates away from the PRR, confirming proper load transfer and expected cantilevered response under launch vibration.

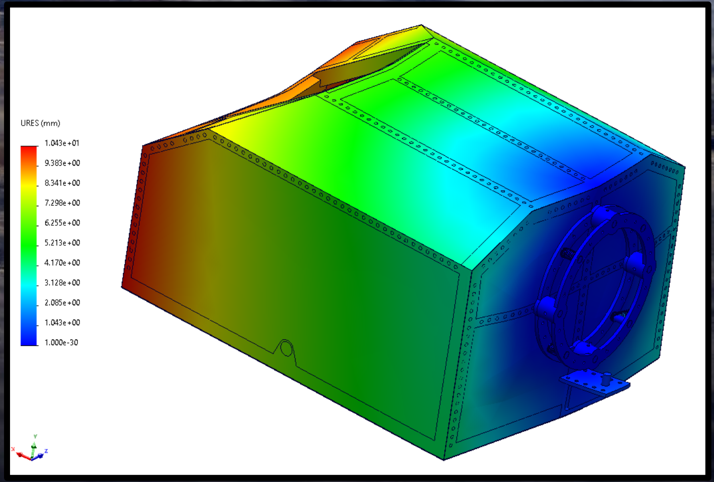
Max deformation: ~10.4 mm (Z-axis)



Random Vibration [X]



Random Vibration [Y]



Random Vibration [Z]

SWaP Summary

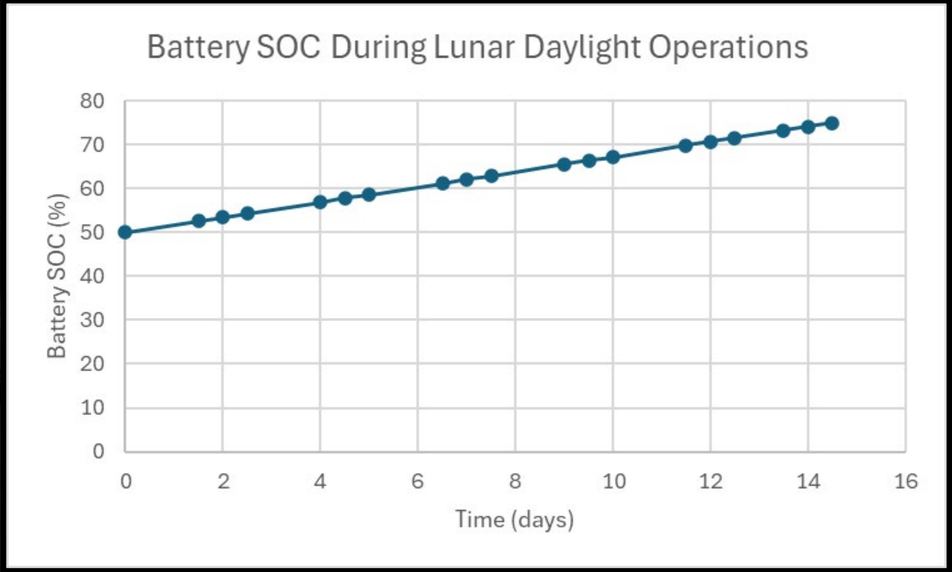
Summary SWaP Table	
Power (W)	1066
Continuous Current (A)	22
Continuous Voltage (V)	221
Mass (kg)	203

Total Payload Budget: 203 kg

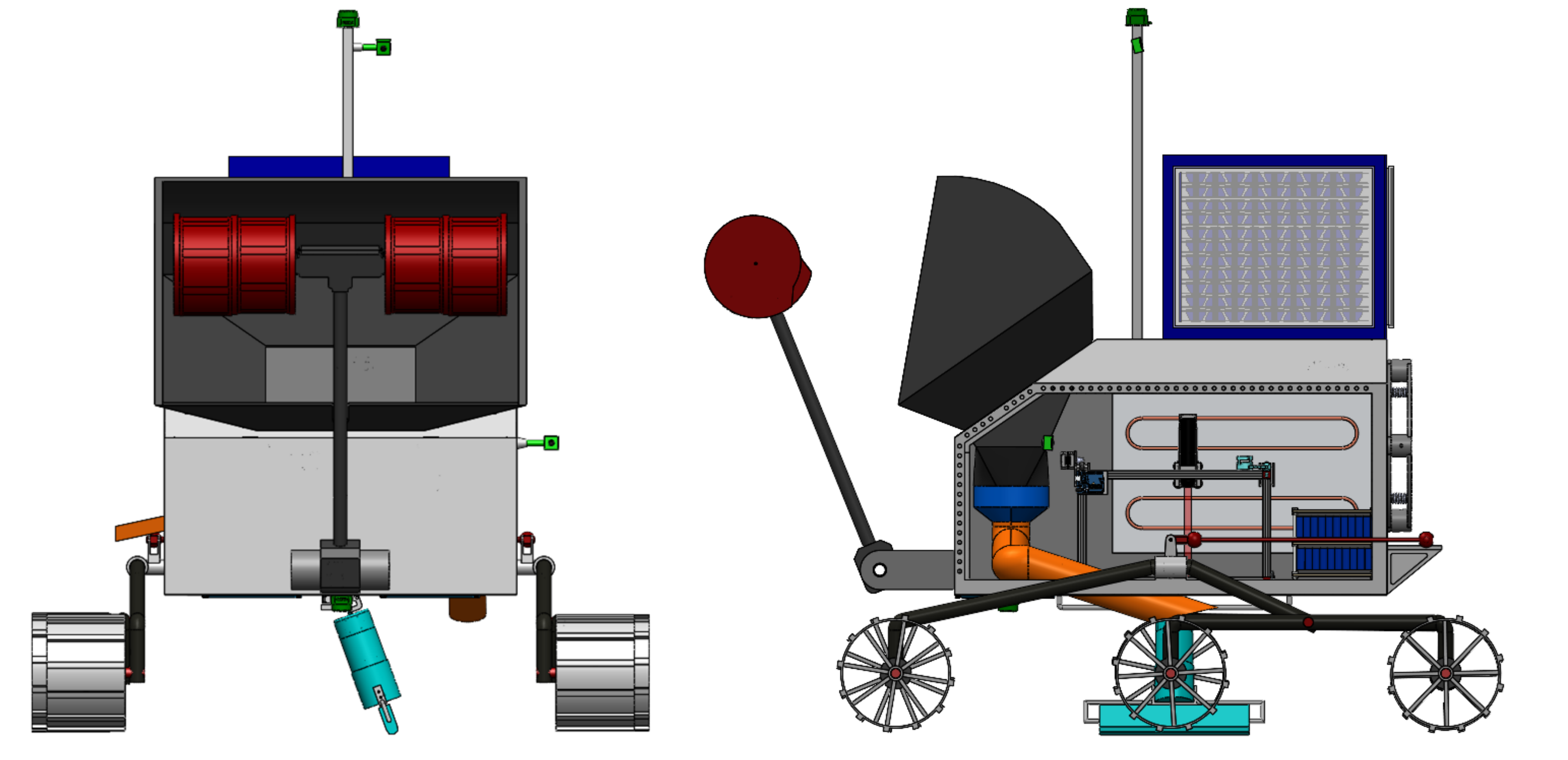
Type	Model	Continuous Voltage (V)	Continuous Current (A)	Power (W)
Linear Actuator	Nema 23	36	1.7	61.2
Linear Actuator	RVMARINEPAT 4"	12	4	48
Servo Motor	40kg High Torque	6.8	4	27.2
Stepper Motor	Nima 17	36	1.5	54
Stepper Motor	Nima 17	36	1.5	54
Stepper Motor	Nima 17	36	1.5	54
Laser Diode		-	-	150
Motor driver	TB6600	6	1.2	7.2
Motor driver	TB6600	6	1.2	7.2
Motor driver	TB6600	6	1.2	7.2
Motor driver	TB6600	6	1.2	7.2
Raspberry Pi	3A+	5	1.4	7
Raspberry Pi	3B	5	1.4	7
Excavator	RASSOR	-	-	275
Motor driver x6	Perseverance	24	2.1	300
TOTAL		220.8	21.8	1066.2

Power Summary

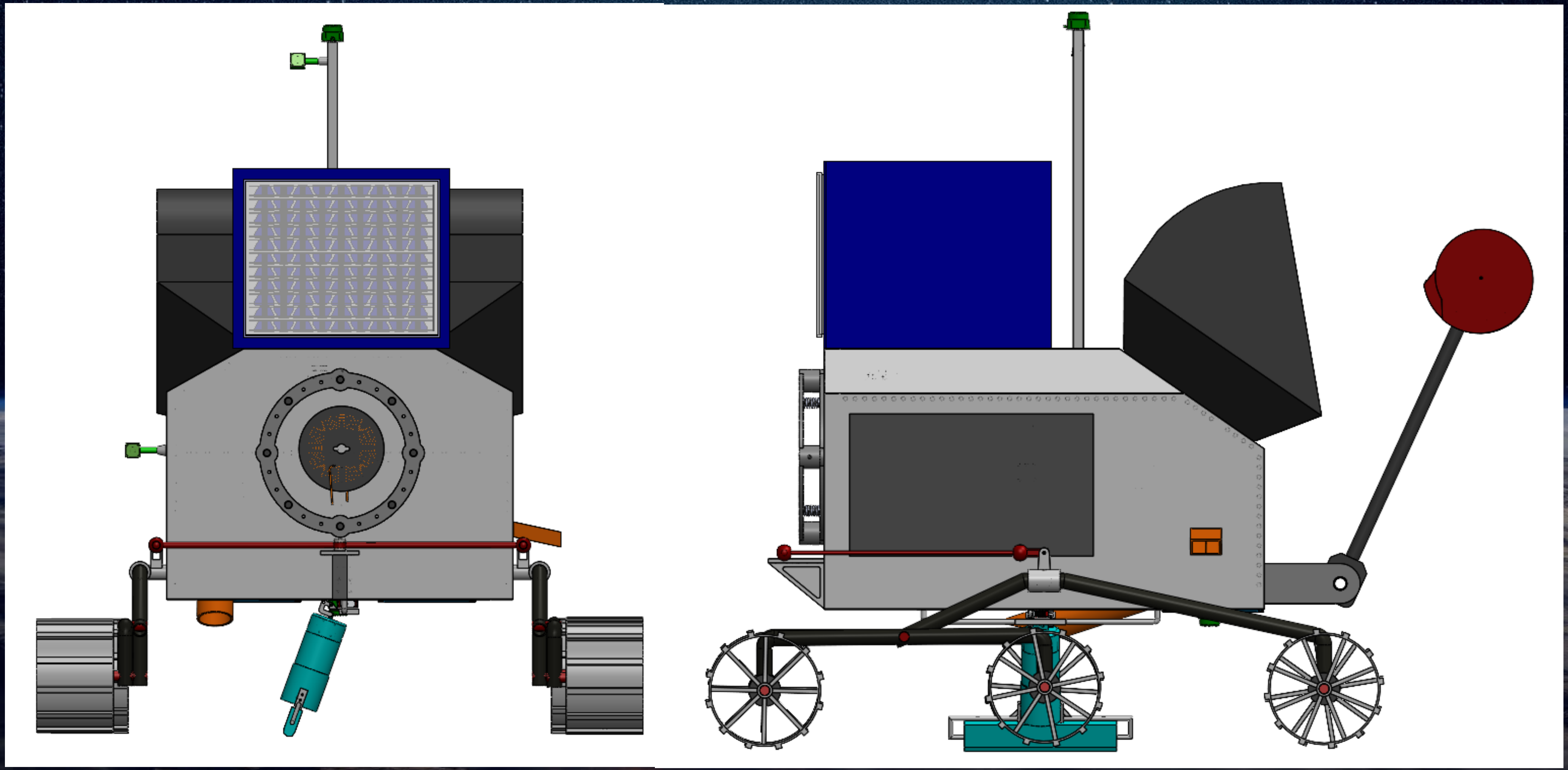
Mode:	Daytime Docking (W)	Deployment to Print Site (W)	Excavation of Regolith (W)	Laser Sintering (W)	Night Survival (W)
Controls [1]	10	20	20	20	5
Mobility	0	80	20	0	0
Excavation	0	0	45	0	0
Laser/AM	0	0	0	280	0
Thermal	5	5	5	10	10
Power Losses	5	5	5	5	2
Requirement	**20**	**110**	**95**	**320**	**17**
Solar Panels [3]	250	250	250	250	0
Battery Assist	0	40	20	70	17
Griffin Induction	10	0	0	0	0
Total Available	**260**	**290**	**270**	**320**	**17**



Additional Views

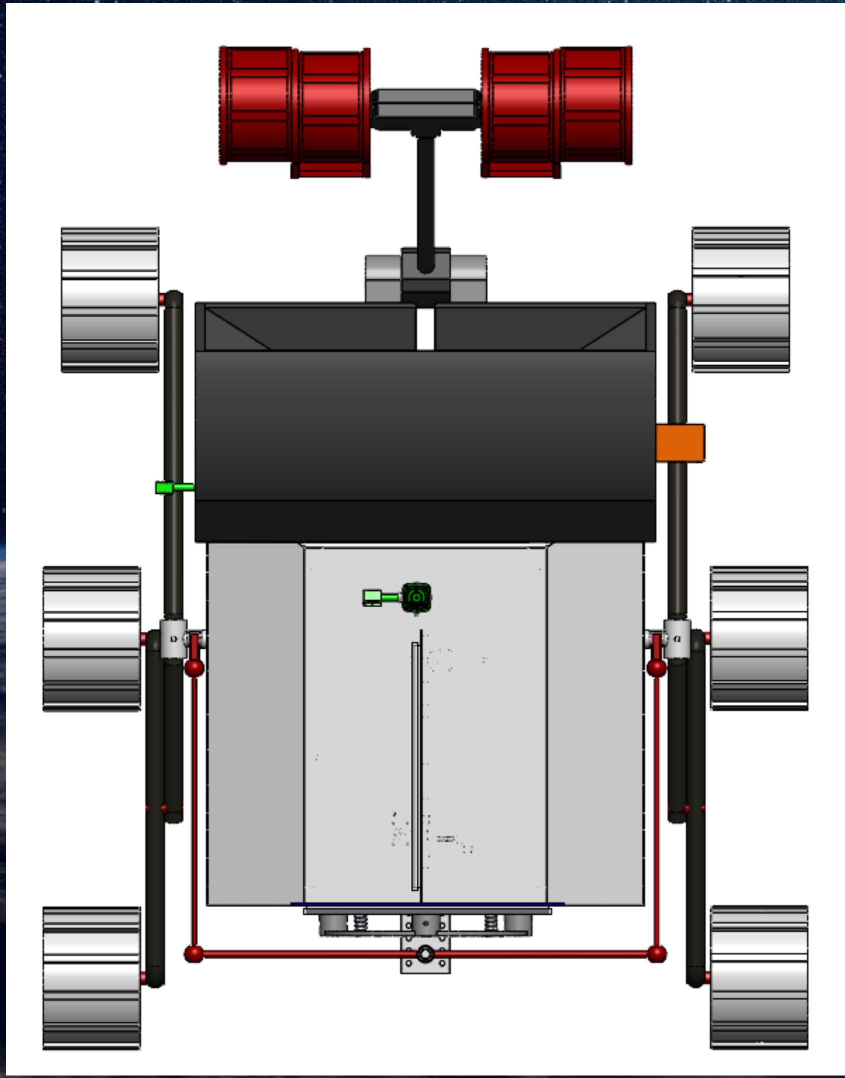


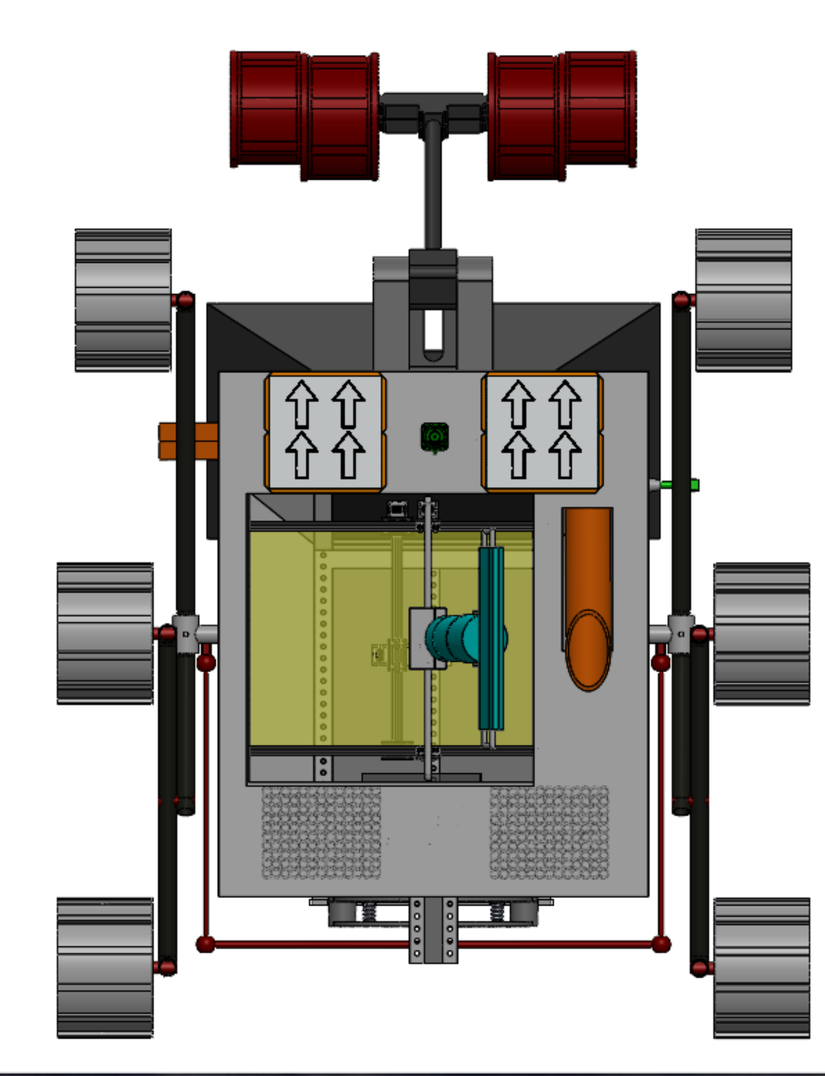
Additional Views



Additional Views

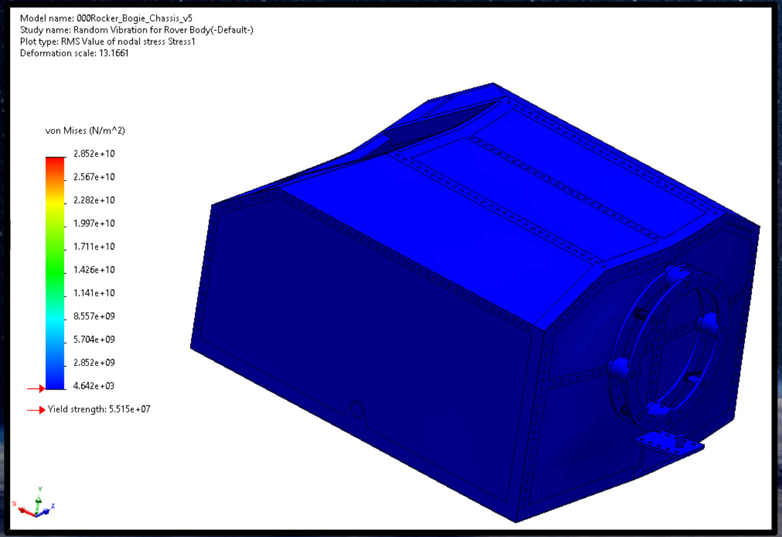
ncep



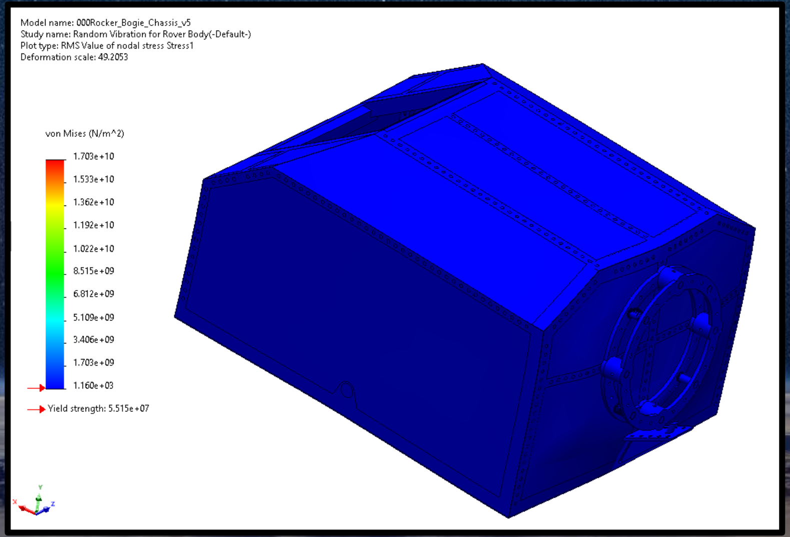


Supplementary FEA for Launch Loads

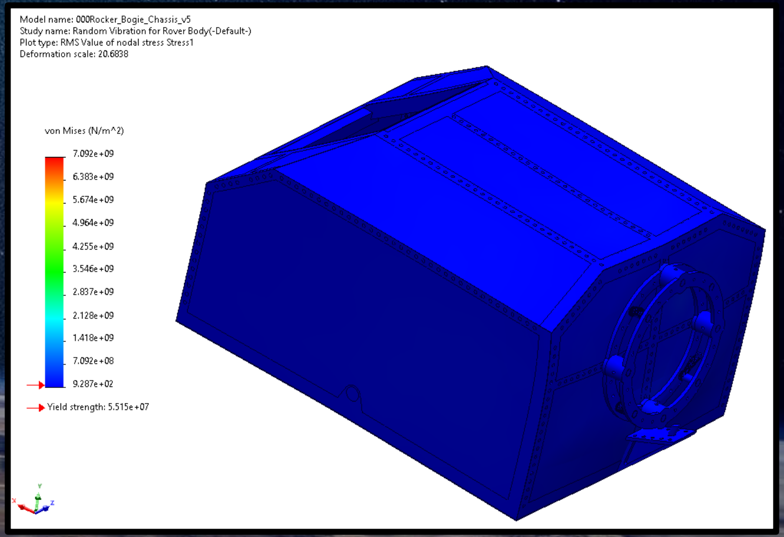
Von Mises Stress from Vibration Analysis



Direction X

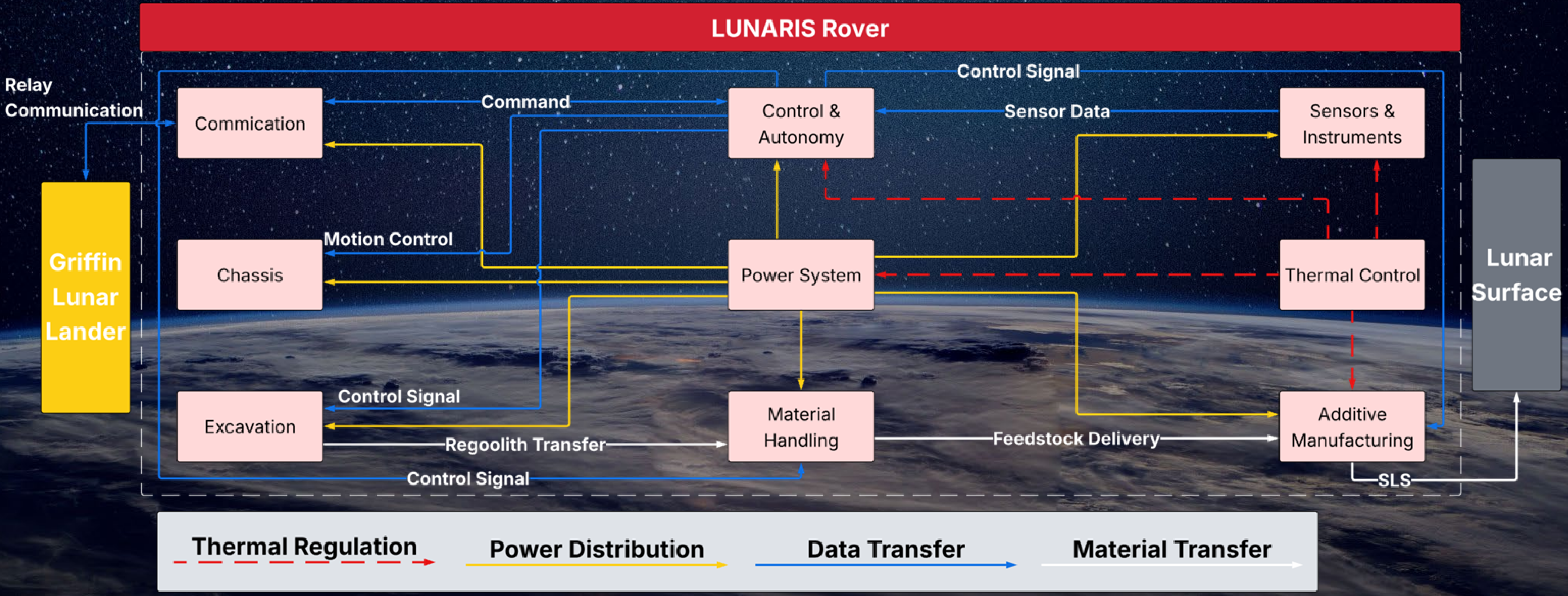


Direction Y



Direction Z

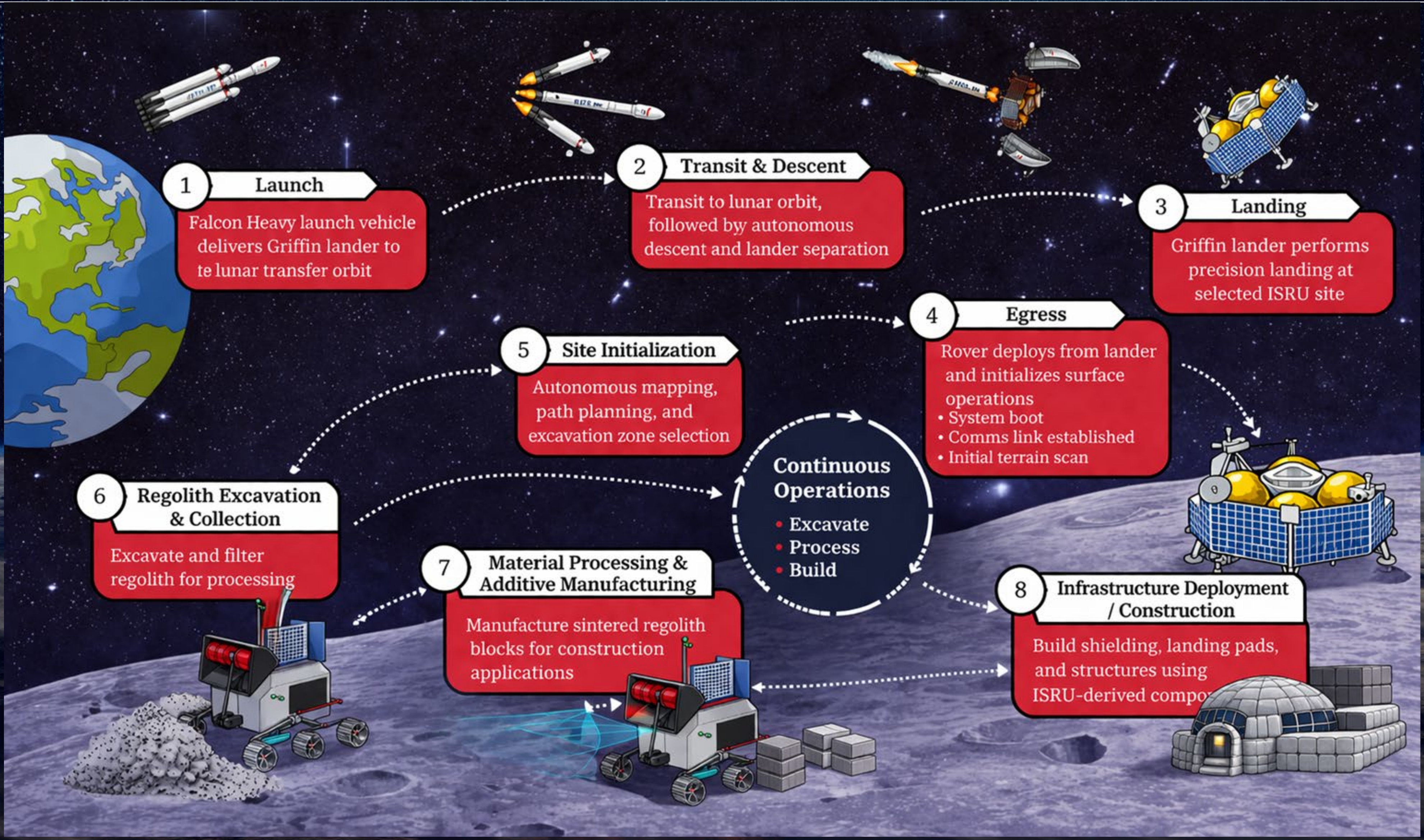
System Block Diagram



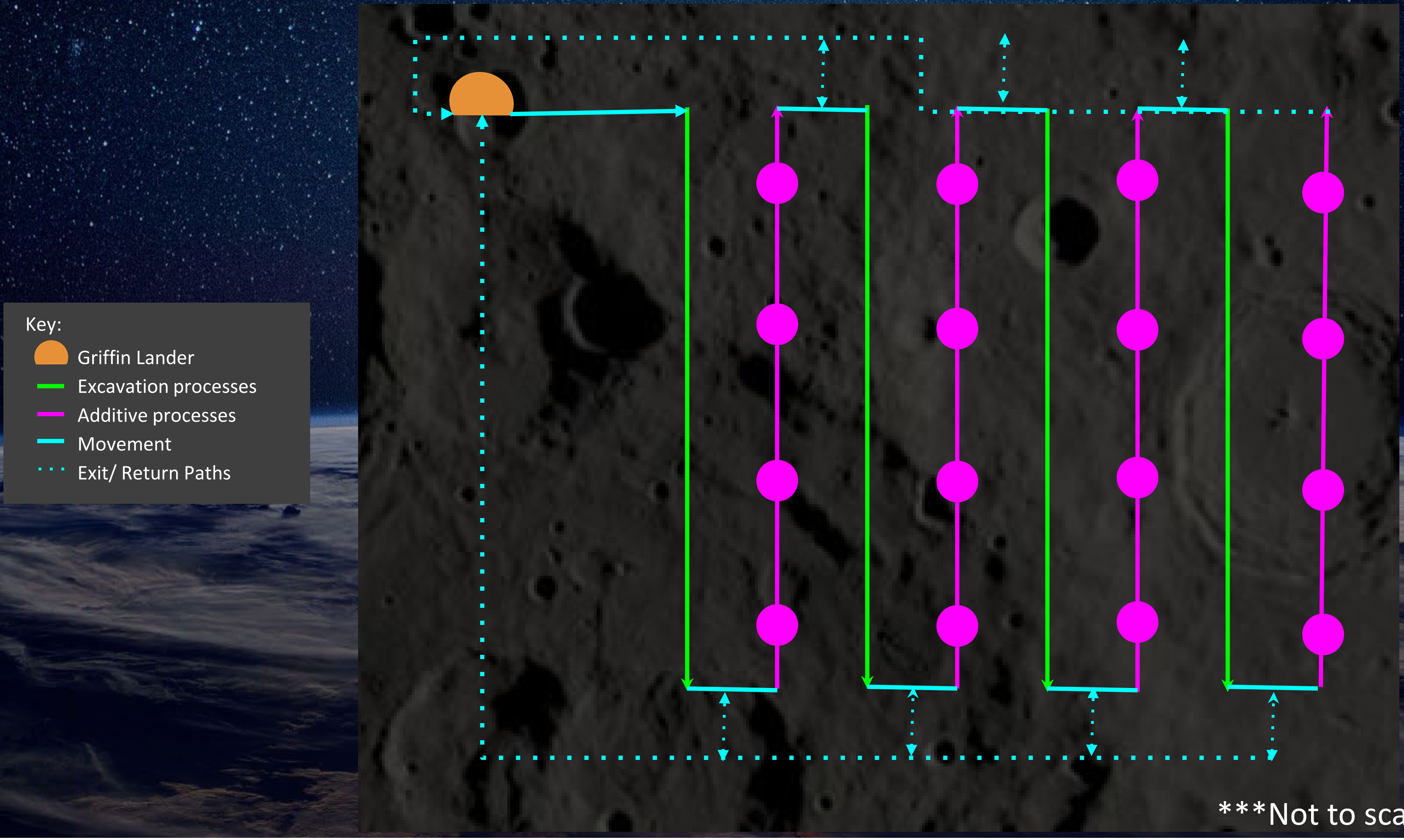
Data Handling & Communication

Block Diagram

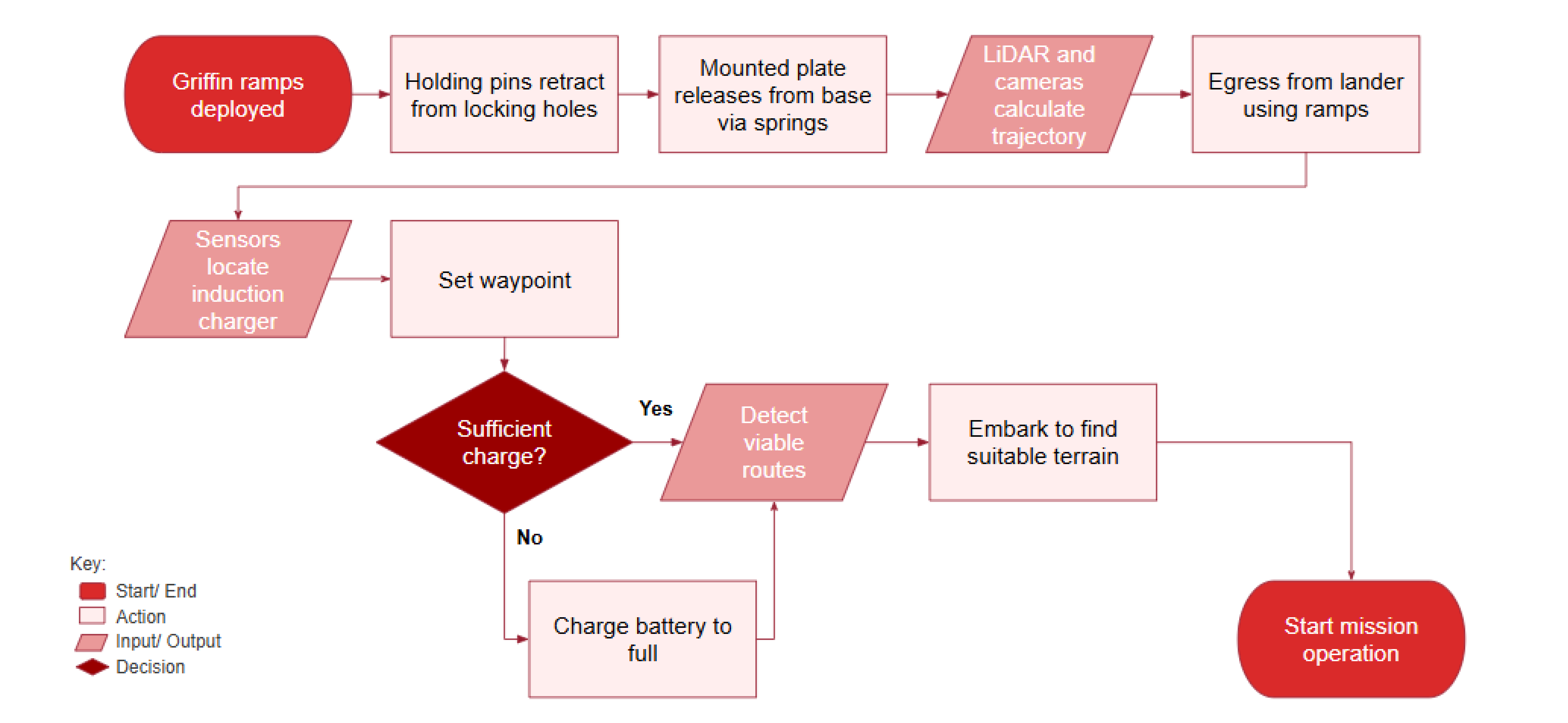
Alternate Storyboard



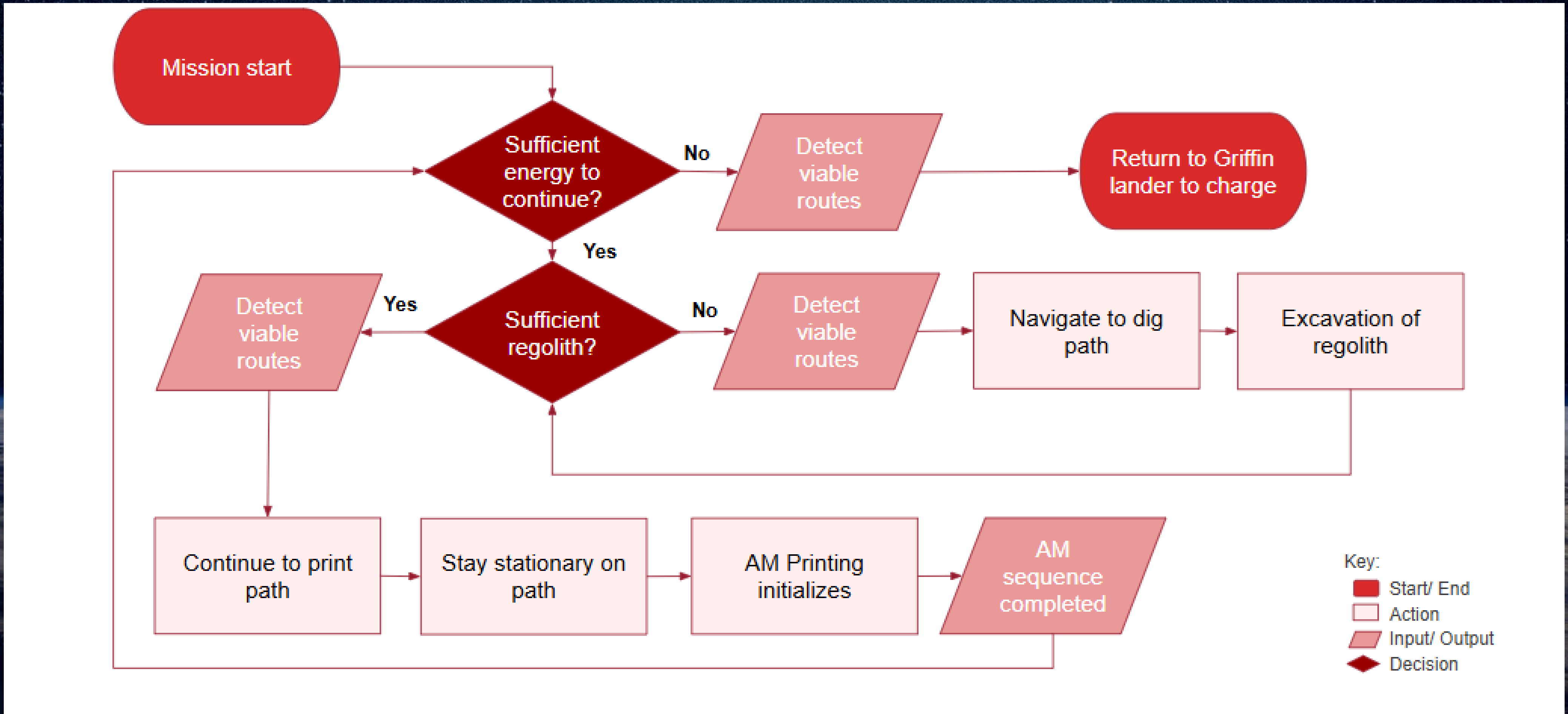
Proposed Operational Traverse Pattern



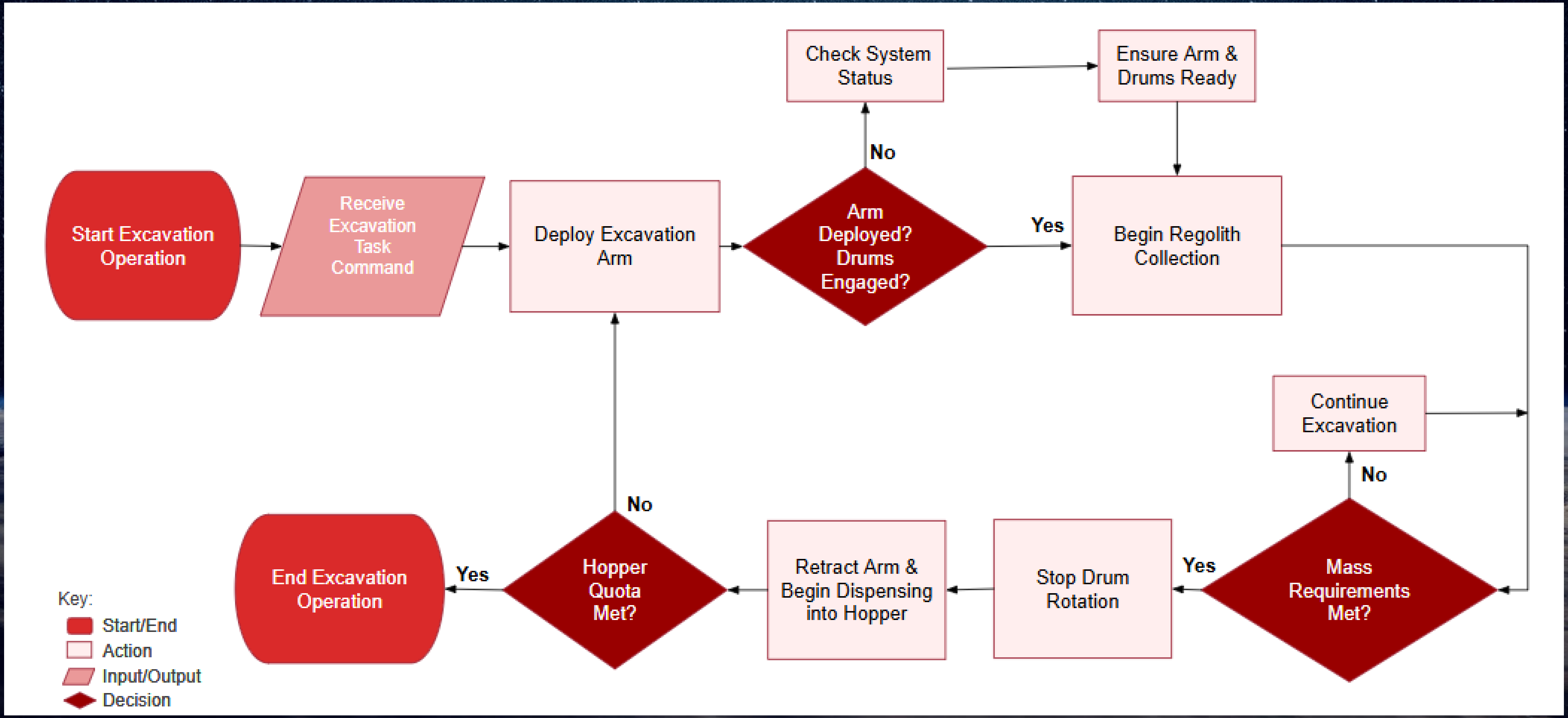
ConOps: Deployment



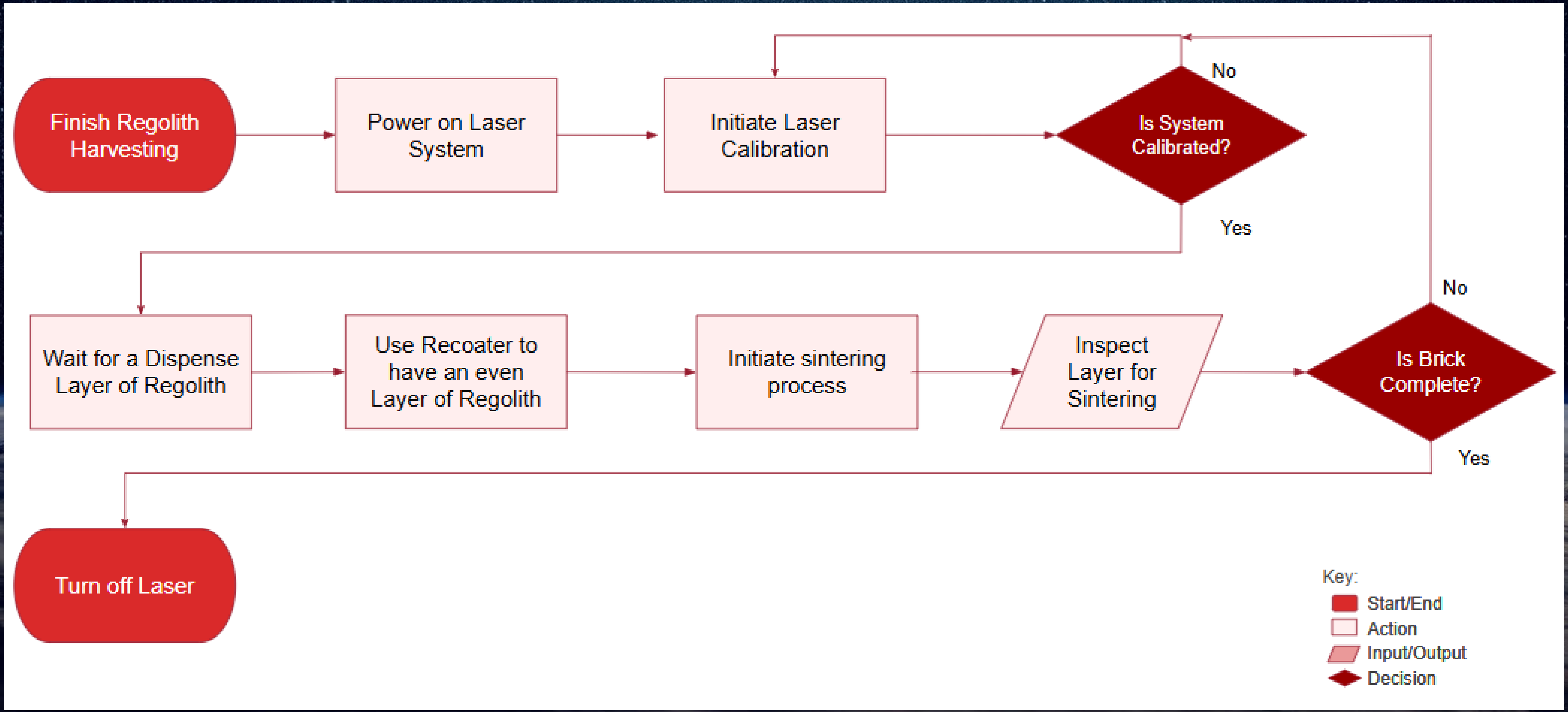
ConOps: General Movement



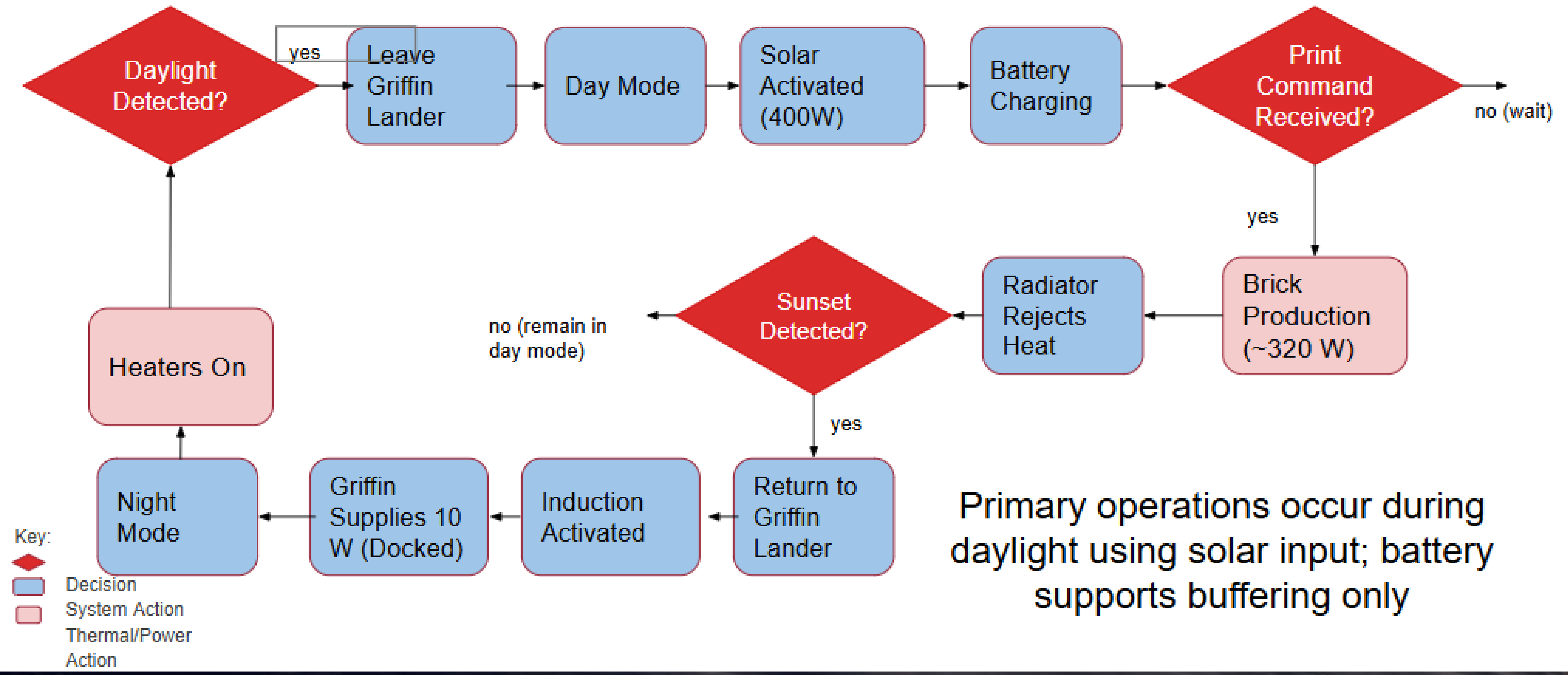
ConOps: Excavation



ConOps: Additive Manufacturing



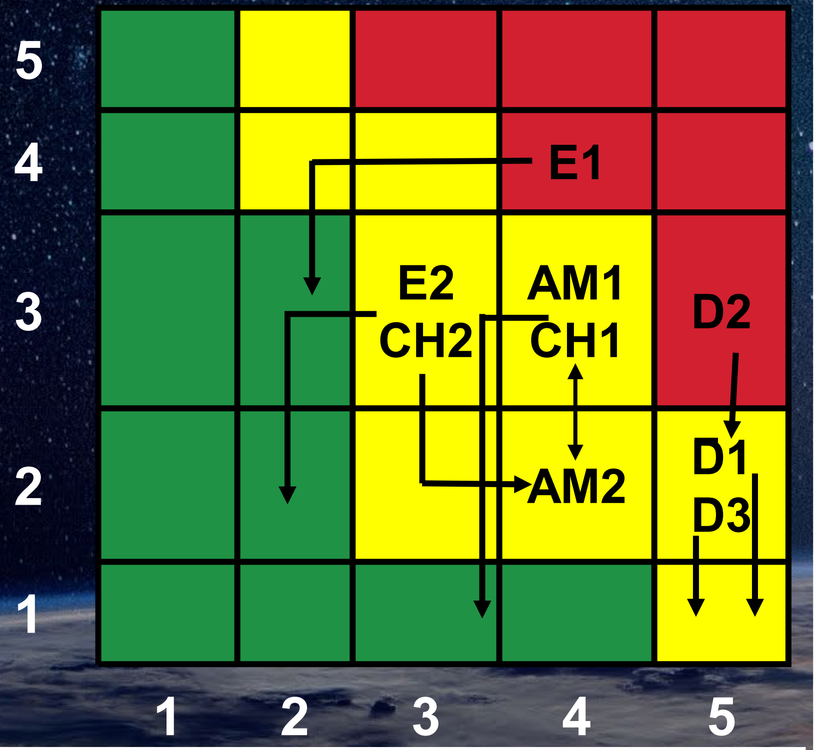
ConOps: Power



Primary operations occur during daylight using solar input; battery supports buffering only

Risks

Likelihood of Failure
Very High 51-100% (5)
High 26-50% (4)
Medium 13-25% (3)
Low 6-12% (2)
Very Low 0.5% (1)



Consequence of Failure	
Catastrophic (5)	Results in total mission failure
Critical (4)	Failure to satisfy several mission requirements
Moderate (3)	Failure to satisfy a mission requirement
Minor (2)	Met mission requirements but disruption to mission timelines
Negligible (1)	Minimal to no impact on the mission outcome

System Risks		Consequences	Mitigation Strategy
D1	Release Mechanism	If the rover fails to deploy via release mechanism, then the mission cannot begin	Use a redundant release mechanisms and test before launch
D2	Battery Depletion	If the battery depletes before charging, then the rover becomes inoperable	Implement minimum battery threshold for rover to return to charge
D3	Mass/Power Exceeded	If mass or power limits are exceeded, then the mission cannot operate as planned	Track mass and power budgets
E1	Regolith Accumulation	If dust accumulates in components, then the systems performance will degrade	Use of EDS mechanisms in prone areas or seal components/covers
E2	Excavation Jam	If the excavation system jams, then materials cannot be collected	Use clearance margins and reverse motors to clear jams
AM1	Thermal Control	If thermal control fails, then electronics may be damaged	Use heaters and radiators to keep components in safe temp zone
AM2	Laser/Recoater Failure	If the laser or recoater fails, uniform layers cannot be produced for the laser and materials cannot be created	Monitor temperature with sensors, reduce weight, and include automatic shutdown
CH1	Mobility Failure	If a wheel or motor fails, then the rover's mobility will be reduced/compromised	Use redundant drive capability to maintain movement if something fails
CH2	Navigation	If navigation fails, the rover may become immobilized or collide with obstacles	Use several sensors around the rover to improve obstacle detection reliability

System Requirements

ID	Function	Requirement Statement	Verification	Description
D1	*Government*	Operation of the payload shall require the authorization and continuing supervision of the United States government (Outer Space Treaty)		
D2	*Government*	The collection and processing of regolith shall not be treated as a claim of lunar territory		
D3	*Government*	The United States government shall be held liable for any damage that the mission may cause to assets belonging to another country during launch		
D4	*Government*	The purpose of the payload shall be made clear to the public and the U.N. Secretary General		
D5	*Government*	The design of the payload shall comply with International Traffic in Arms Regulations (ITAR) and Export Administration Regulations (EAR)		
D6	*Government*	The launch of the payload shall seek both the review and approval of the U.S. Federal Aviation Administration (FAA)		

System Requirements

ID	Function	Requirement Statement	Verification	Description
D7	***Government***	The payload shall transmit data via the appropriate frequency bands decided by the Federal Communications Communication (FCC)		
D8	***Government***	The payload shall operate within designated safety zones to avoid interference with activities performed by other operations		
D9	***Government***	The manufacturing process shall not contribute to the contamination of the lunar surface		
D10	***Government***	Ownership of bricks and processed regolith shall be allowed under the terms of the U.S. Commercial Launch Competitive Act 2015		

System Requirements

ID	Function	Requirement Statement	Verification	Description
CC1	***COSMIC Capstone Challenge***	The payload shall be operable with a total mass under 200kg		
CC2	***COSMIC Capstone Challenge***	The payload shall be operable with a volume ¾ of the total volume TBD of the Griffin lunar lander payload bay.		
CC3	***COSMIC Capstone Challenge***	The payload shall operate in the lunar south pole region.		
CC4	***COSMIC Capstone Challenge***	The system shall have a target operation life 100 days on the lunar surface.		
CC5	***COSMIC Capstone Challenge***	The system shall be operable within the extreme temperatures of the lunar surface (120°C to -130°C).		
CC6	***COSMIC Capstone Challenge***	The system shall operate in a vacuum environment		
CC7	***COSMIC Capstone Challenge***	The payload shall mitigate the hazards of operating on regolith.		
CC8	***COSMIC Capstone Challenge***	The system shall disperse excess heat to keep hardware in tolerable TBD temperature		

System Requirements

ID	Function	Requirement Statement	Verification	Description
H1	***Hazard Mitigation***	The system shall use radiation and conduction to remove excess heat produced by the laser.	Analysis	Specifies passive heat rejection compliant with vacuum environment.
H2	***Hazard Mitigation***	The system shall use low outgassing, vacuum rated materials.	Inspection	Ensures material durability and cleanliness under vacuum.
H3	***Hazard Mitigation***	The system shall mitigate dust intrusion via Electro-Dynamic Shielding(EDS).	Analysis	Protects optics, sensors, and joints from lunar dust interference.
H4	***Hazard Mitigation***	The system shall utilize coatings to protect the rover from material degradation.	Analysis	Protects optics, sensors, and joints from lunar dust interference.
H5	***Hazard Mitigation***	The system shall utilize seals to prevent regolith dust from entering internal mechanisms.	Analysis	Protects optics, sensors, and joints from lunar dust interference.

System Requirements

ID	Function	Requirement Statement	Verification	Description
CS1	***Software and Control Systems***	The system shall control payload command execution, autonomous capabilities, and data handling.	Test	
CS2	***Software and Control Systems***	The system shall manage communication between the payload and the Griffin lunar lander.	Test	
CS3	***Software and Control Systems***	The system shall control the path of additive manufacturing to create fundamental building blocks.	Test	
CS4	***Software and Control Systems***	The system shall adjust power, operation time, and speed of the additive process.	Test	
CS5	***Material Processing Software***	The system shall classify regolith by particle size and composition.	Test	
CS6	***Material Processing Software***	The system shall continuously adjust the regolith feed rate.	Test	
CS7	***Material Processing Software***	The system shall capture data from sensors and detect regolith and obstacles using AI.	Demonstration	

System Requirements

ID	Function	Requirement Statement	Verification	Description
E1	***Particle Excavation***	The excavation system shall be capable of gathering and handling bulk material efficiently.	Inspection	
E2	***Particle Excavation***	The bucket drum shall have a maximum mass of 5 kg.	Inspection	Defines excavation rate and dust control efficiency.
E3	***Particle Excavation***	The bucket drum shall not exceed a diameter of 360 mm.	Inspection	
E4	***Particle Excavation***	The bucket drum shall not exceed a length of 320 mm	Inspection	
E5	***Particle Excavation***	The bucket drum shall capture a minimum regolith volume of 16.5 liters.	Test	Ensures mechanical containment meets volume and load specs.
E6	***Particle Excavation***	The system shall transport collected regolith to the designated storage unit.	Test	Specifies regolith conveyance between collection and storage modules.
E7	***Particle Storage***	The storage container shall be capable of holding a minum of 25 kg of regolith.	Analysis	Ensures material collection accuracy and prevents contamination.

System Requirements

ID	Function	Requirement Statement	Verification	Description
E8	***Particle Storage***	The storage system shall be designed for durability and repeated operational use.	Analysis	Ensures reliability under lunar vacuum, dust, and radiation.
E9	***Particle Storage***	The storage system shall enable controlled transfer of regolith further for processes.	Test	Protects internal systems during extreme temperature shifts.
E10	***Particle Placement***	The system shall separate or reject regolith that does not meet specified quality or composition criteria.	Test	Supports uniform bed layering for additive manufacturing.
E11	***Particle Placement***	The recoater shall deposite equal volumes of material during each dispensing operation.	Inspection	

System Requirements

ID	Function	Requirement Statement	Verification	Description
AM1	***Powder Based Printing***	The sintering system shall produce building blocks with a minimum compressive strength of 10 MPa.	Test	Defines baseline mechanical performance of printed structures.
AM2	***Powder Based Printing***	The gantry system shall have a work area able to accommodate bricks with a rectangular geometry.	Inspection	
AM3	***Powder Based Printing***	The sintering system shall use a 120 W diode laser to enable the bonding of lunar regolith particles at 1200 °C.	Test	
AM4	***Powder Based Printing***	The sintering system shall operate using a diode laser with a wavelength of 1.06 µm.	Analysis	
AM5	***Laser Movement and Optimization***	The system shall control the position of the laser with a two-axis gantry system.	Demonstration	Defines the method of tool manipulation using proven technologies.
AM6	***Laser Movement and Optimization***	The laser optics system shall mechanically control the focus of the laser using a lens or prism.	Test	Defines the method of maintaining target beam width.
AM7	***Laser Movement and Optimization***	The laser optics system shall maintain desired beam width while minimizing power or path inefficiencies.	Test	Specifies control tolerances for optical and kinematic precision.

System Requirements

ID	Function	Requirement Statement	Verification	Description
AM8	***Laser Movement and Optimization***	The sintering system shall reserve a portion of the laser output for regolith preheating.	Analysis	Manages thermal gradients during the sintering phase and preserves hardware lifespan.
AM9	***Laser Movement and Optimization***	The laser shall move at a speed able to maintain target temperature on the ground while staying in motion until a shape is completed.	Demonstration	
AM10	***Laser Cooling***	The cooling system shall maintain the laser at a safe and functional temperature range throughout process.	Test	Regulates laser subsystem temperature for reliability.
AM11	***Product Material Reactions***	The system shall heat regolith to at least 1200 °C but no more than 1600 °C and maintain temperature ±100 °C while under load.	Test	Ensures material sintering achieves consistent structural bonding.
AM12	***Product Material Reactions***	The sintering system shall remain under 45 °C for entire process.	Analyze	
AM13	***Debris Mitigation***	The system shall reduce debris during production.	Test	Minimizes contamination risk to sensors and other neighboring equipment.

System Requirements

ID	Function	Requirement Statement	Verification	Description
AM14	***Debris Mitigation***	The system shall be fully enclosed to prevent debris from interfering with sensitive moving parts.	Inspection	Keeps abraisive regolith from entering moving hardware and interfering with laser performance.
AM15	***Debris Mitigation***	The system shall minimize plume size during production	Test	
AM16	***Debris Mitigation***	The system shall deploy an EDS systems to clean and possibly prevent regolith build-up	Test	
AM17	***Recoater***	The recoater system shall spread layers with a thickness uniformity of ±5% across the work area prior to sintering.	Test	
AM18	***Recoater***	The recoater system shall deposit equal volumes of material during every dispensing sequence with 90% accuracy	Test	
AM19	***Recoater***	The recoater system shall operate despite pervasive regolith contamination.	Demonstration	

System Requirements

ID	Function	Requirement Statement	Verification	Description
CH1	***System Deployment***	The payload shall mount via an adapter plate that provides the mechanical interface to the Griffin lander.	Inspection	Defines structural interfaces and load constraints.
CH2	***System Deployment***	The payload attachment plate shall be able to withstand a maximum vibrational load of 22749 N.	Analysis	
CH3	***System Deployment***	The payload attachment plate shall be able to withstand a maximum acoustic load of 2440 N/m^2.	Analysis	Defines deployment sequence and detachment mechanism.
CH4	***System Deployment***	The payload attachment plate shall be able to withstand 1176728.1 N of shock loads.	Analysis	
CH5	***System Deployment***	The payload should detach from the adapter plate via controlled release.	Inspection	Specifies the type of ramp that will be used to deploy the system
CH6	***System Deployment***	The payload shall egress using the VIPER ramps provided the Griffin Lunar Lander.	Demonstration	Explains how the ramps will unfold and connect to create a straight path for the system

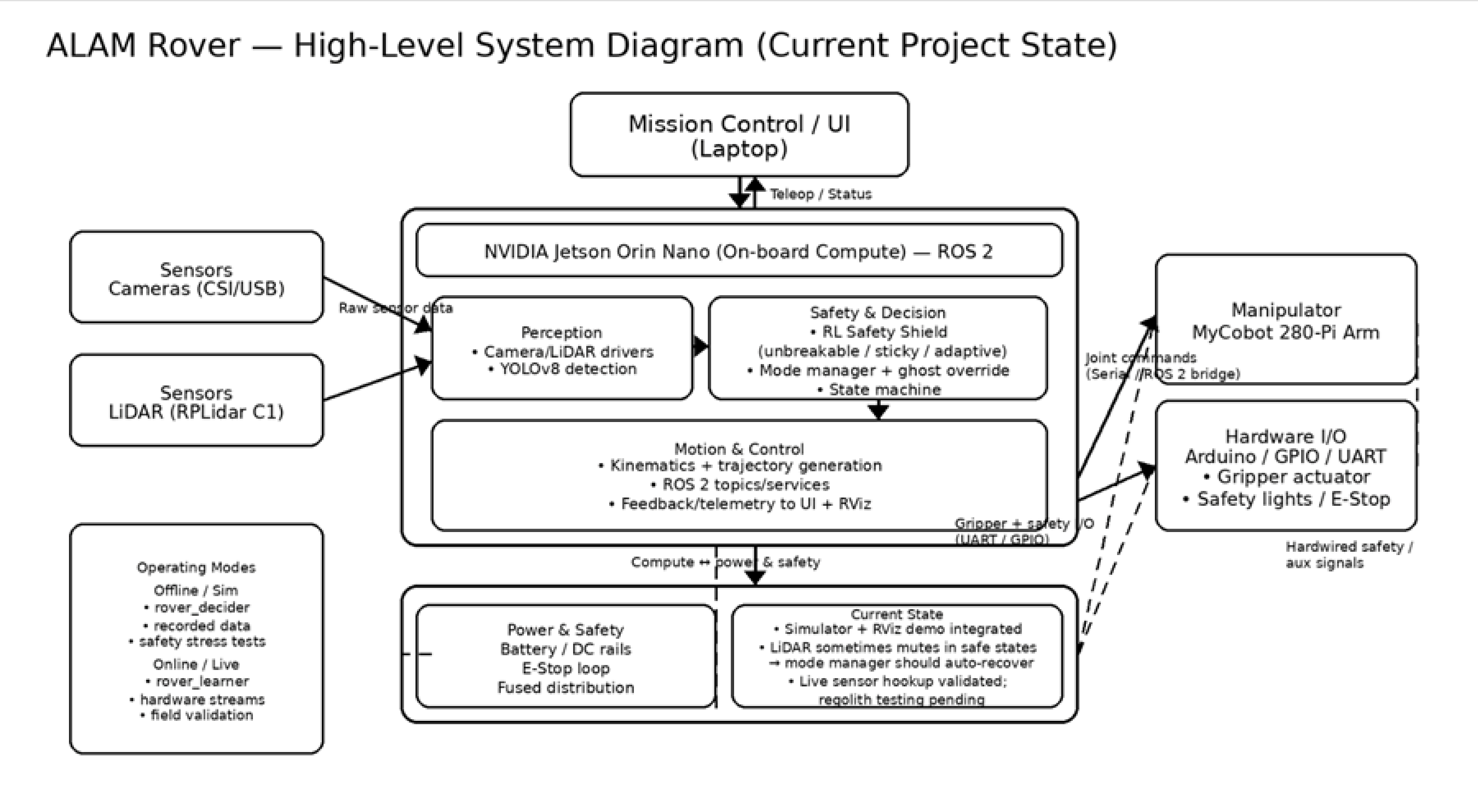
System Requirements

ID	Function	Requirement Statement	Verification	Description
CH7	***System Mobility***	The rover shall utilize 6 wheel independent drive for movement.	Inspection	Explains the type of steering the rover will use to perform
CH8	***System Mobility***	The rover shall utilize a rocker suspension to traverse uneven terrain.	Inspection	Specifies what region the rover shall be able to traverse
CH9	***System Mobility***	The rover shall move at an average of 0.01 m/s to minimize dust kick up.	Demonstration	
CH10	***System Mobility***	The rover shall be capable of ascent/descent up to 30º of slope (+/- 5º cross-slope) without slippage.	Demonstration	
CH11	***System Mobility***	The wheels shall be able to traverse around boulders with a diameter of 0.30 m or more.	Demonstration	

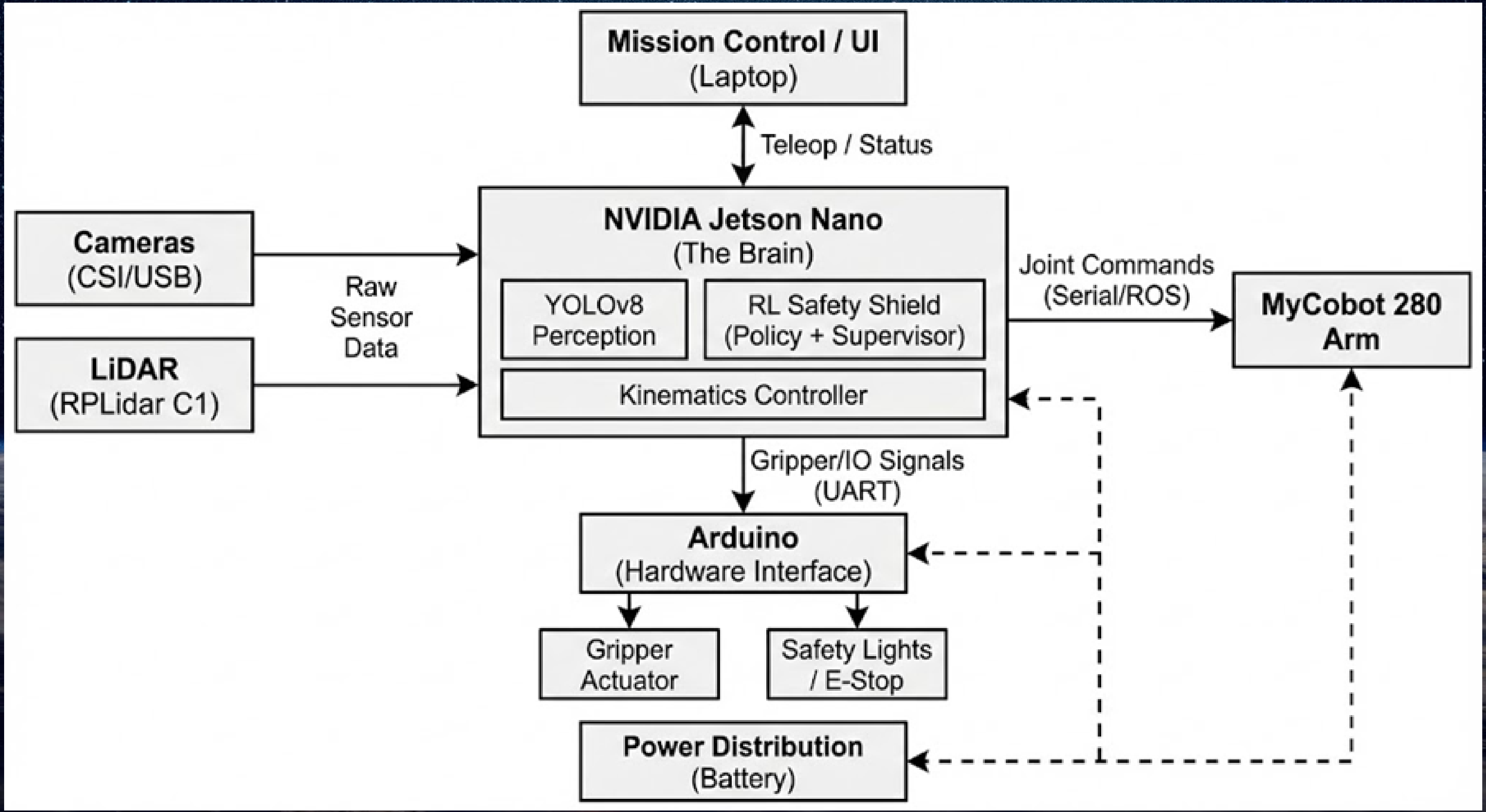
System Requirements

ID	Function	Requirement Statement	Verification	Description
CH12	***Power Consumption***	The system shall be able to recharge via induction charging.	Test/Demonstration	Specifies energy source, lifetime, and subsystem power sharing.
CH13	***Power Consumption***	The system shall take 2 hours or less to fully charge using induction.	Analysis	Outlines solar input and energy regulation strategy.
CH14	***Power Consumption***	The system shall employ solar panels during daytime operation for additional charging.	Inspection	
CH15	***Power Consumption***	The system shall register AC voltage for power necessities.	Inspection	Specifies another energy source that shall be used to charge the system

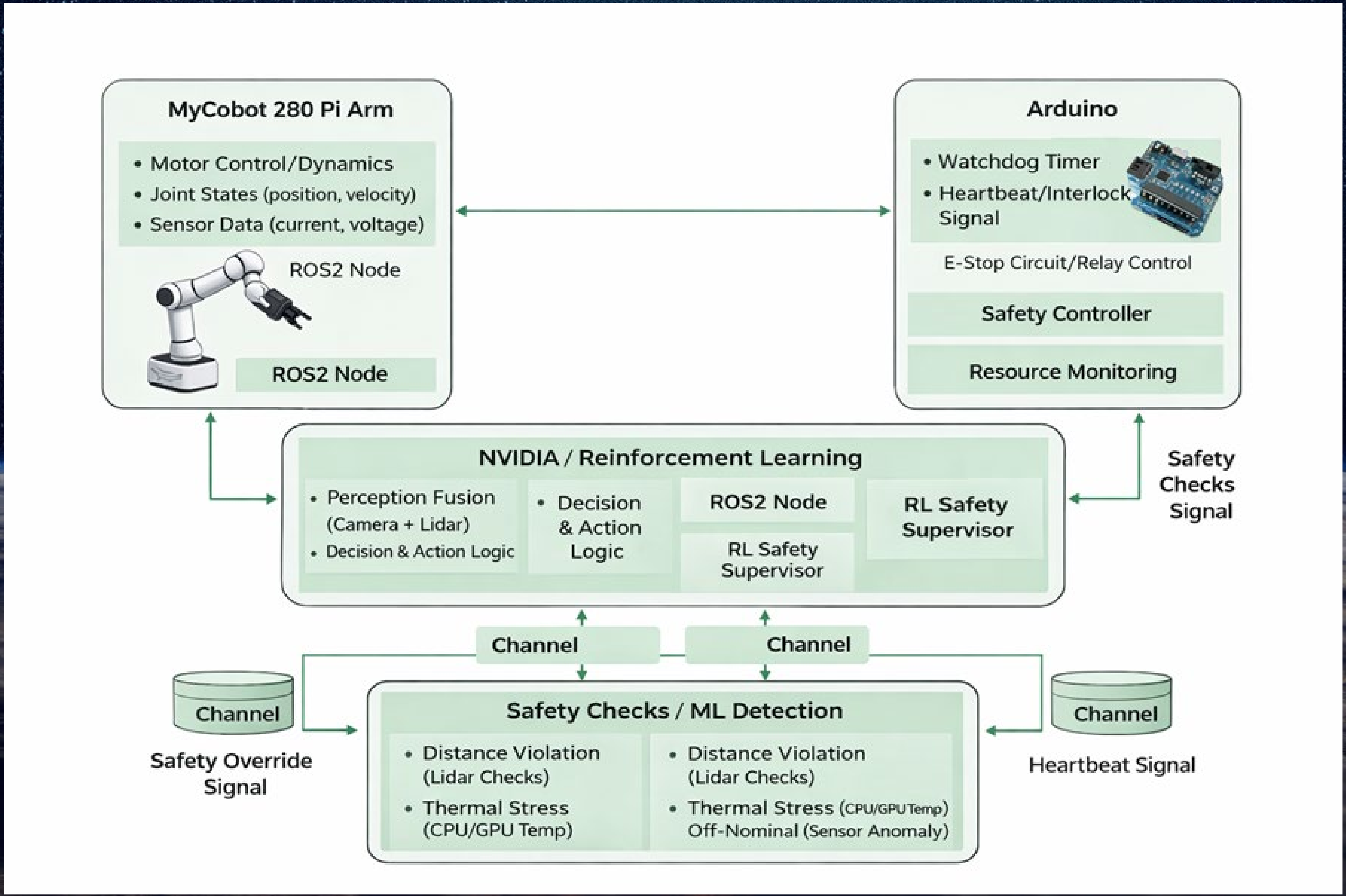
Controls System Diagram



Controls System Architecture



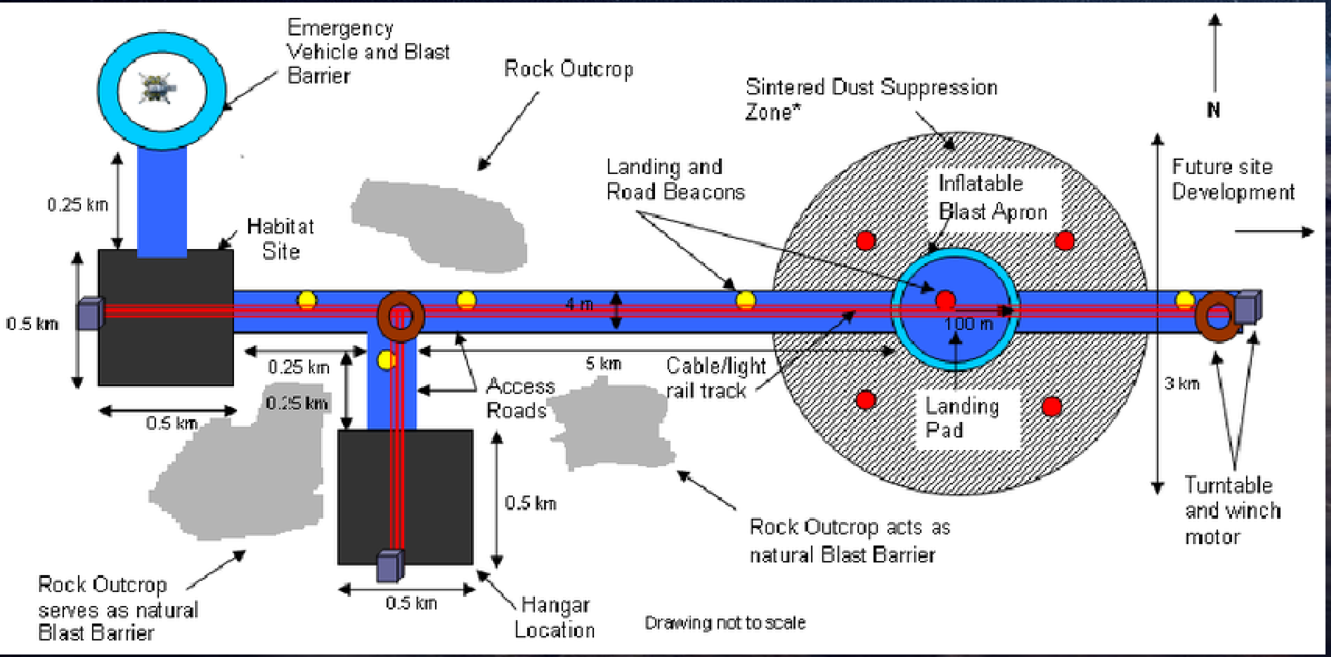
Controls Software Architecture

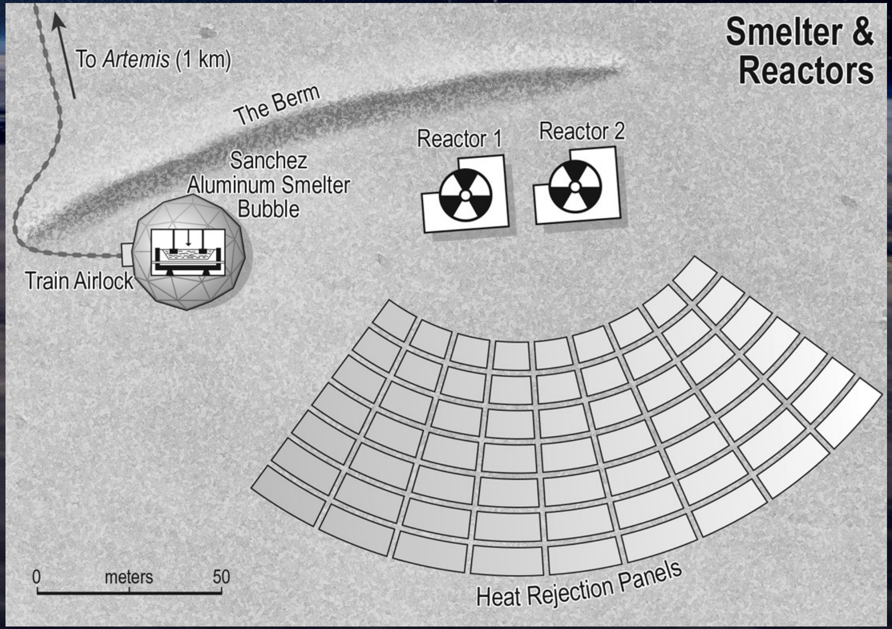


Impact of Operation

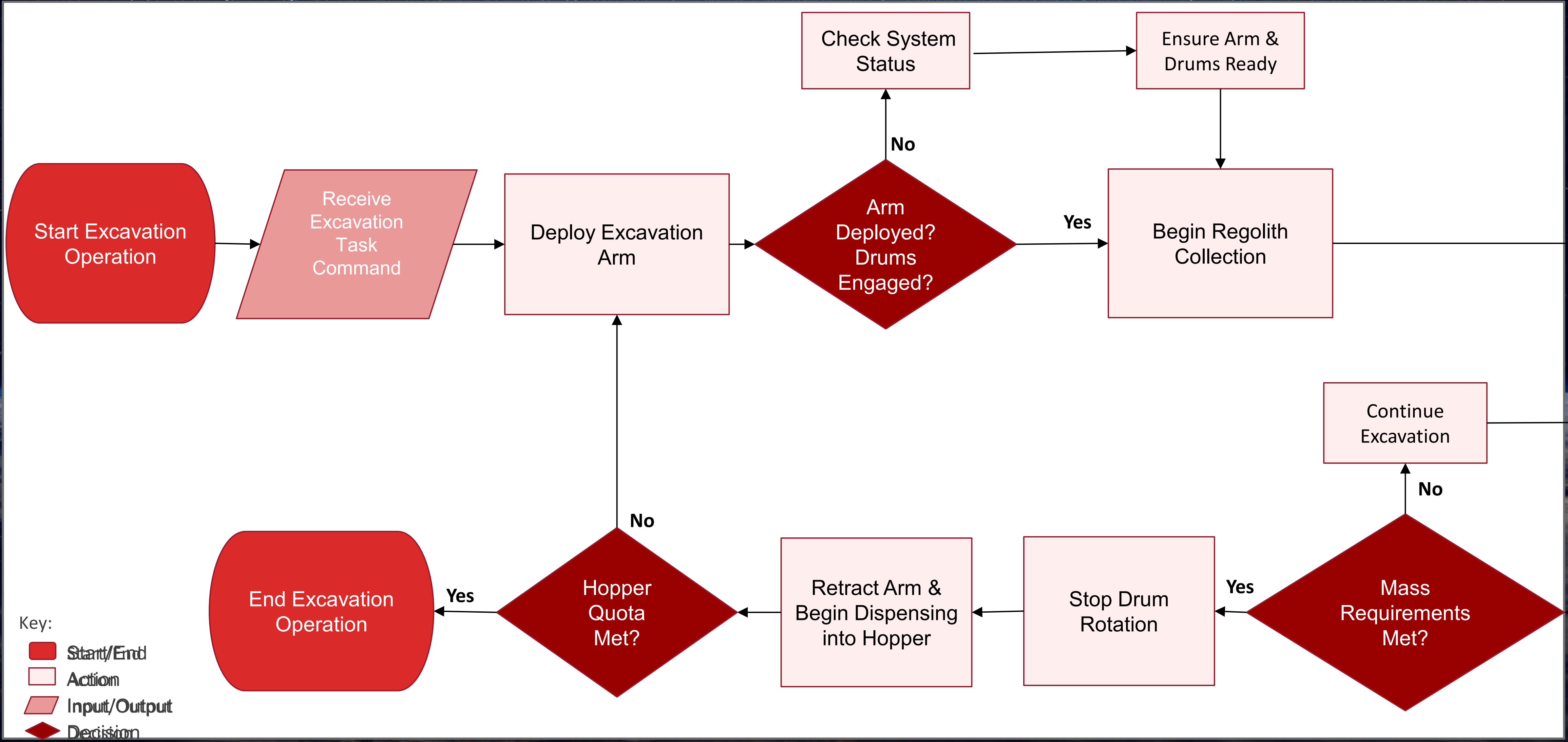
Examples of infrastructure that could be constructed:

- Landing pads
- Road pavements
- Tiles for domes
- Berms
- General construction





Concept of Operations: Excavation



Trade Hopper

Criteria	Conical Hopper Silo	Truncated Cone	Open Rectangular Bin	Rectangular Crate
Mass flow reliability (%)	86	80	35	74
Actual Slope (°C)	60	50	90	50
Vacuum Compatibility (%)	95	90	20	85
Dust Release During Filling (mg/s)	30	60	300	50
Control Feed Rate (kg/s)	6	20	0.8	55
Max Flow Rate Outlet (kg/s)	5.4	19.5	0.12	254.6
Abrasion Resistance	5/10	7/10	7/10	7/10
Thermal Range (°C)	-173 to 127	-173 to 127	-173 to 127	-173 to 127
Volume Capacity (m^3,kg)	0.170	0.121	0.250	0.152
Empty Mass (kg)	20.4	33.4	53.5	49.5
Estimated Cost (ROM) ($)	6000	7000	2000	8000
Selection		✅		

Design Reference Missions

Decision Criteria	NASA IPEx	NASA RASSOR	Earth Excavator Bucket	ISAM 2026 Excavator
Mission Objective	Lunar ISRU	Lunar/Mars Regolith Ops	Industrial Excavators	Lunar Regolith Excavation
Excavation Architecture	Counter Rotating Bucket Drum	Counter Rotating Drums	Rotary bucket	Counter Rotating Drums
Low-Gravity Stability	Designed for Lunar Gravity	Tested for Reduced Gravity Ops	Designed for 1g(not suitable for reduced gravity)	Designed for Lunar Gravity
Reaction Force Mitigation	Yes	Yes	No	Yes
Demonstration Environment	Lunar Simulant Testing	Simulant Testing	Earth Field Operations	Prototype Phase/Regolith Simulant
TRL	5	4	9 (Earth)	5

AM Trade-off Studies

Gantry System Options			
Decision Criteria	**Designing a Custom Friction-Based System**	**Utilizing a Belt and Pulley Design**	**Modifying an Existing 3D Printer**
Low Cost	$14.99, 3D Print	$26.58	$219.00
Number of Parts	5, 3D Print	26	1(preassembled)
Power (W)	4.2	18	12
High Scalability	41.91 x 41.91 mm + 3D Print	41.91 x 41.91 mm + 21 parts of 160.53 mm on average	406.4 x 304.8 x 457.2 mm
Weight	0.399 kg, 3D Print	0.481 kg	7.12 kg
[illegible]		✓	

- The gantry system allows the laser to move in a 3D axis for sintering regolith bricks.
- Independent designs and modifying an existing 3D printer add too much complexity to the gantry system, using a belt and pulley system simplifies the design.

AM Trade-off Studies

Recoater System Options		
Design Criteria	**Blade Recoater**	**Roller Recoater**
Power Consumption (W)	< 5	10-20
Mass (kg)	3-5	6-10
Layer Uniformity (mm)	±0.3 - 0.6	±0.2 - 0.4
Wear Rate	1x	5x
Normal Force (N)	5-10	20-70
Selected	✅	

- A recoater will control powder layer uniformity and packing density, directly affecting the parts strength and integrity.
- A blade system would be able to mechanically spread the regolith more uniformly than a roller and wear down at a slower rate.

AM Trade-off Studies

Sintering pattern options			
Design Criteria	**Continuous Linear Exposure**	**Full Plate Exposure**	**Section Plate Exposure**
Power Efficiency	~80%	~50%	~60%
Printing Time	Standard	~3x longer	~2.5x longer
Motors (moving parts)	4	1	4
Program complexity	G-Code	Timer system	Timer system & G-Code
Design Flexibility	Upgradeabl e	Static	Limited
Selected	✅		

AM Trade-off Studies

Lasers options			
Criteria	**Fiber Laser**	**Diode Laser**	**CO_2 Laser**
Weight	50-100kg	15kg	22–45kg
Power	500W	333W	1000W
Size	660.4 x 457.2 mm	5.588 x 3.81 mm	5.588 x 3.81 mm
Cost	$1,500 – $4,500	$250 - $1,500	~$1,500 – $2,000
Selected		✅	

AM Trade-off Studies

Regolith Mitigation options				
Decision Criteria	Nylon/ Fiberglass Brush	Electrodynamic Dust Shield (EDS)	Pressurized Gas	Vibration
Weight	0.28g+ attachments	1.1 kg	0.08g-260g	7.71kg-18.14kg
Power	<1 W	2-8W	<1W	10-50W
Cost	$6.99 + attachments	???	$517-$1,870	$100-$15,000
Size	127x12.7x12.7mm + attach	4,743.7 mm^3	106,182.2 mm^3	230,000 mm^3
Selected		✅		

SWAP Analysis (Size, Weight, and Power)

Component	Mass (kg)	Peak Power (W)	Role
Li-ion Battery (6.6 kWh Capacity)	33.0	—	Night survival + load buffering
Solar Panels (Deployable)	7.5	400 W (expected)	Power changes depending on Sun angle, dust, and temperature; 500 W is the maximum in full sunlight
Radiator Panels	4.0	0	Heat rejection into space
Loop Heat Pipes	1.8	0	Move heat around inside
Kapton Heaters	0.7	10 W (night)	Keep robot from freezing
Power Electronics	2.8	5–10 W loss	Control and distribute power
TOTAL	49.8 kg	320 W peak load	—

Power & Thermal Mission Expectations

Parameter	Expected Values	Notes
No-Sun Survival Duration	348 hours (1 lunar night)	Big Battery; Strong Heaters Necessary
Peak Electrical Load (W)	~320	Laser Sintering Mode
Total Operational Energy	~105 kWh per lunar day	Daytime Work Energy
Night Survival Energy	~3.48 kWh	Avionics (Brain) + Heaters
External Temperature Range	−130°C to +120°C	Moon is Extreme
Heat Rejection Method	Radiation to Space	No Air on Moon

Battery Trade Study Evaluation

Decision Criteria	Hydrogen Nickel Ion	Lithium Ion	NanoTritium Batteries
Heritage	Moderate	High	Very Low
Nominal Voltage (V)	1.25	3.7	1
Watts-hour/Kg	24	160	-
Life	30 years	10 years	20 years
Watts-hour/L	128	393	10
Selected		✅	

Battery Sizing and Configuration & Night Survival

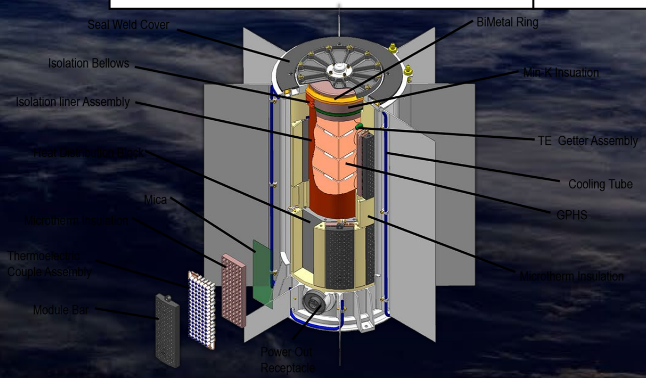
Parameter	Requirement	Selected Design	Notes
Night Load	10 W	10 W	Avionics (brain) + heaters
Night Duration	348 hr	348 hr	Lunar night period
Energy Needed	3.48 kWh	3.48 kWh minimum	10 W × 348 hr
Battery Capacity	Atleast 3.48 kWh	~6.6 kWh	extra safety for power spikes and backup
Bus Voltage	48V system	48V nominal	System power level
Cell Layout	13S40P Li-ion	13S40P Li-ion	~140 Ah class
Mass	Under 40kg limit	~33 kg	~200 Wh/kg assumption
Thermal Strategy	Prevent freezing	heat pipes, insulation, heaters	Maintain operating temp

Thermal Management Trade Study

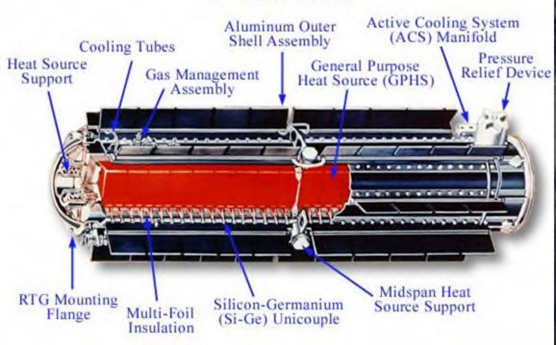
Decision Criteria	Multi-Layer Insulation + Radiators	Multi-Layer Insulation + Kapton Resistive Heaters	MLI + Heat Pipes + Kapton Resistive Heaters	Active Pumped Loop (EHD Pump) + Heat Pipes
High Daytime Stability	-	+	+	+
Lunar Night Survivability	-	+	+	+
Low Night Power Consumption	+	-	+	-
Low Integration Complexity	+	+	+	-
Low Mass	+	+	+	-
High TRL/Heritage	+	+	+	-
Sum of Positives	4	5	6	2
Sum of Negatives	2	1	0	4

RTG Trade Study Evaluation

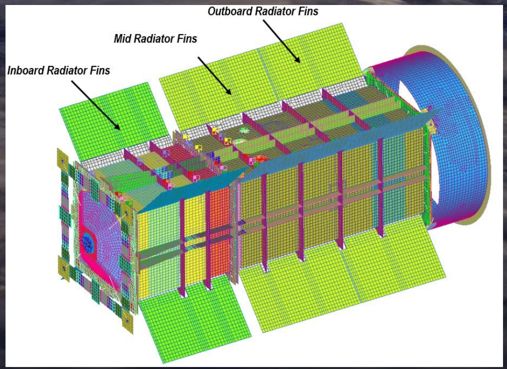
Decision Criteria	Multi Mission RTG	General Purpose Heat Source RTG	Advanced Stirling RPS	Enhanced MMRTG
Heritage	Multiple Missions	+	None	+
Watt generation per unit	110	245	4	4
Specific Power (W/Kg)	2.8	5	8	4
Life	14+	14+	14	14+
Weight	45 kg	55kg	20-25 kg	50 kg



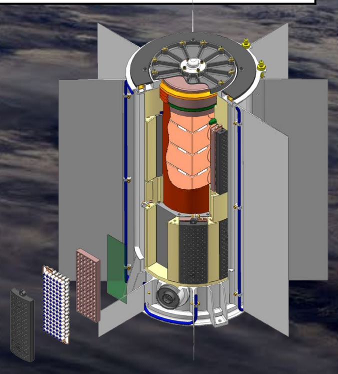
MMRTG



GPHS-RTG



AS RPS


e-MMRTG