



C3 Cosmic Flexion

Team Members

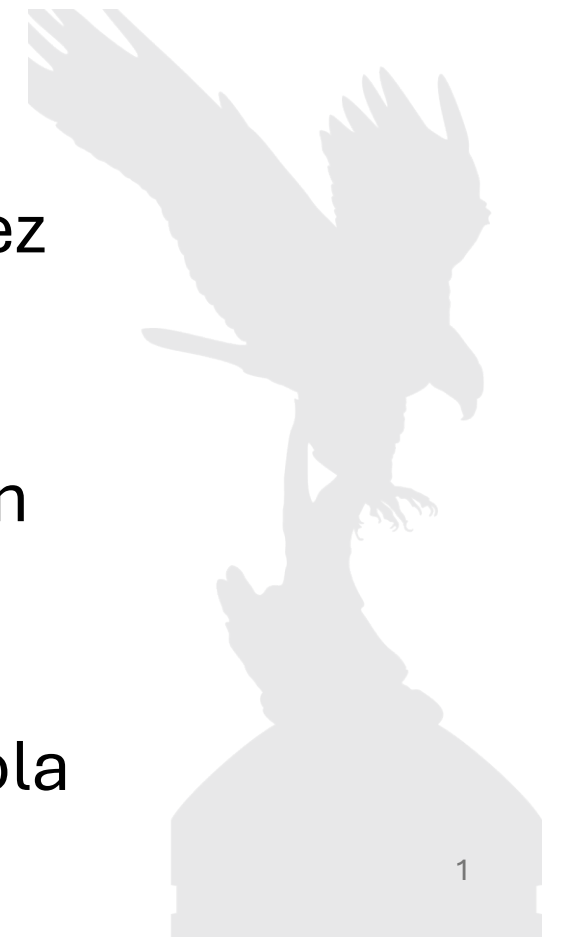
- William Dortch
- Matthew Loi
- Jonathan Sanchez
- Kin Tsang

Advisor

- Michael Thorburn

Mentor

- Horace Lee
- Antonella S. Pinola





Meet the Team

Matthew Loi

- Mission Requirement
- High-level System Design
- Solar Tower Layout and Performance

Kin Tsang

- Outfitting
- Assembly
- Automation

William Dortch

- High-level System design
- Wireless Charger Design

Jonathan Sanchez

- Mechanical analysis
- Outfitting



Executive Summary

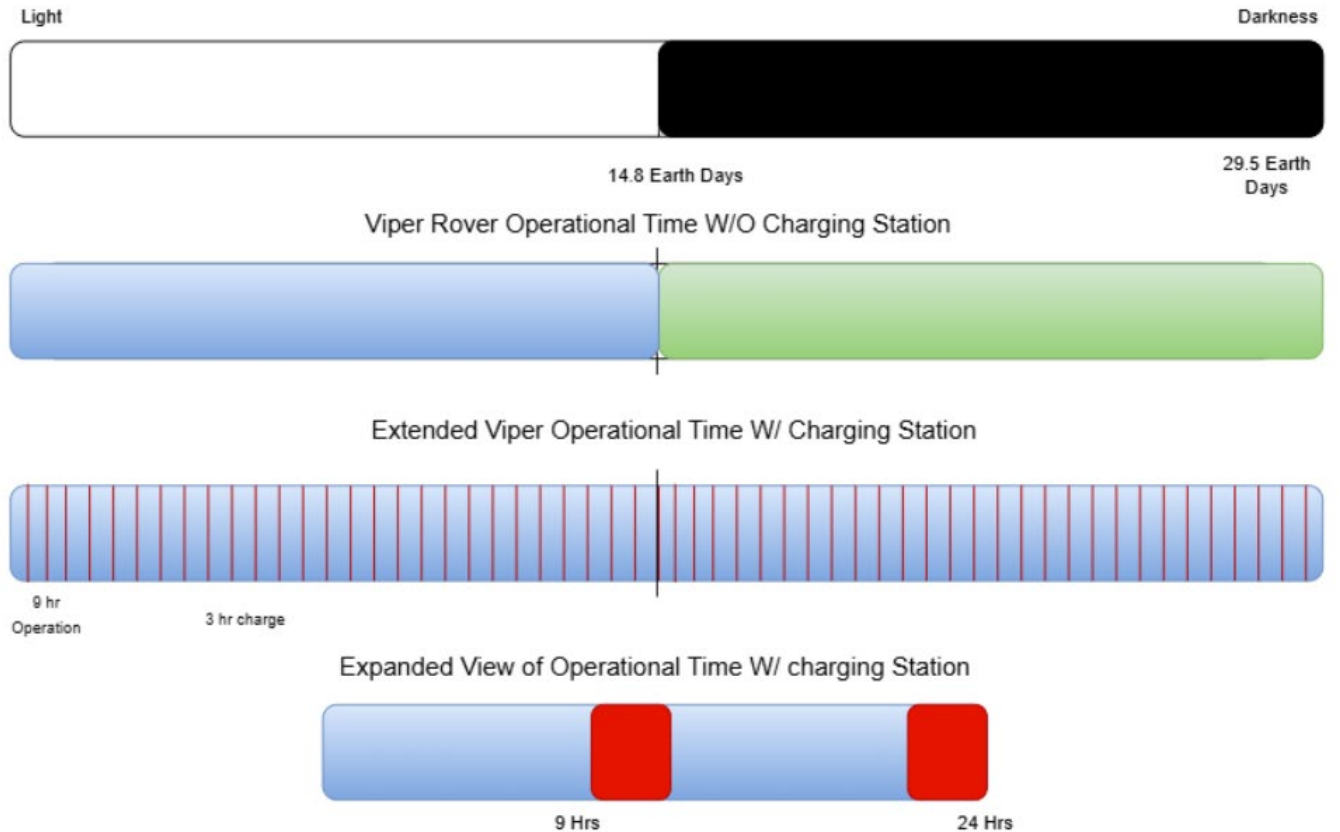
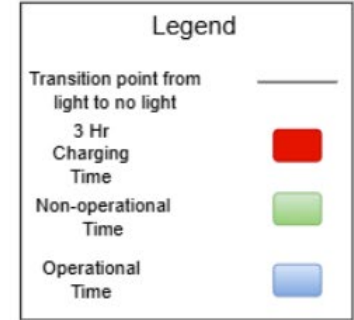
- **Problem**
 - Extracting Lunar resources require energy
 - Short Operational and Mission time
 - No available light in Craters
 - Solar Panels Vulnerable to Dust Accumulation
- **Solution**
 - Generate and Store Energy for Wireless Charging
- **How it Tackles Problem**
 - Reduces need for complex energy systems
 - Extend Rover and Mission Operational Time



Operational Time Benefit

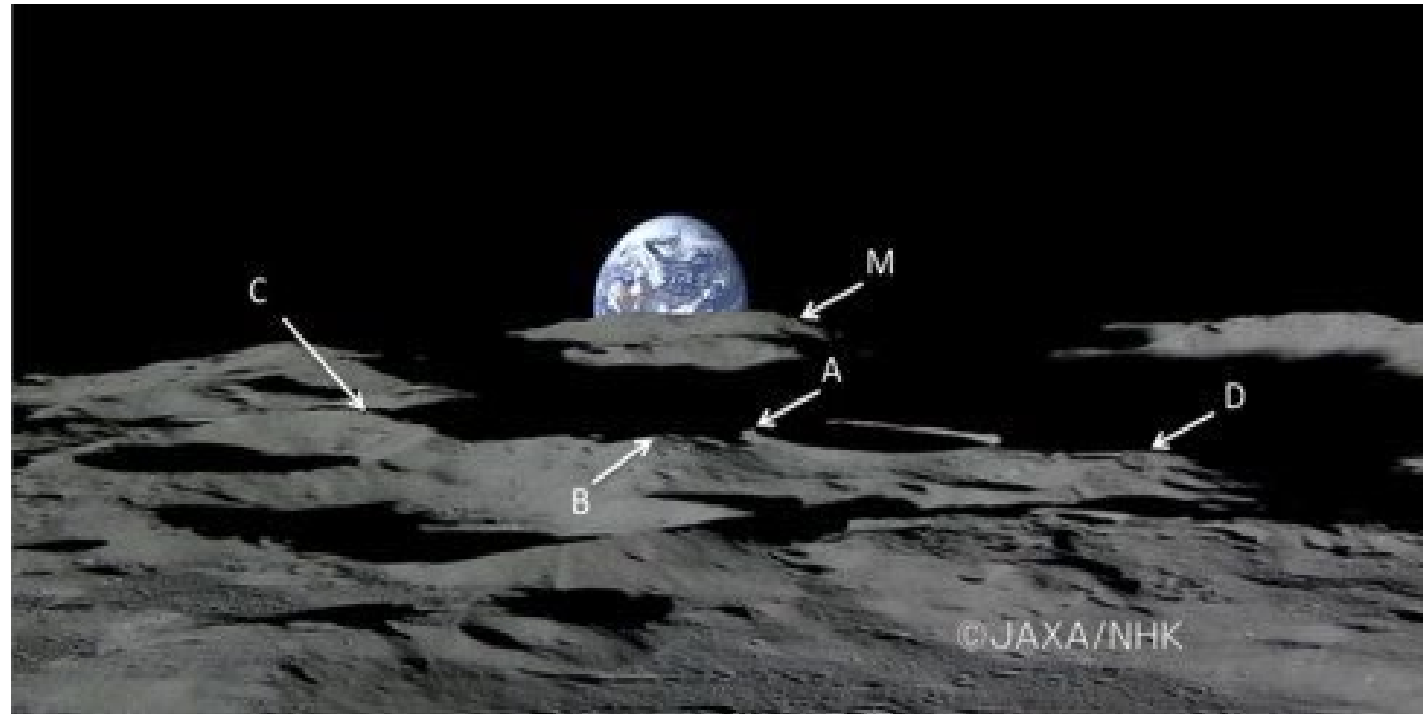
- Rover operation ends with darkness
- Per day Rover uptime is 18hrs (75%)

| | Operational Time |
|----------------------------|---------------------|
| Rover W/O Charging Station | 355.2 hrs per cycle |
| Rover W/ Charging Station | 531 hrs per cycle |



Shackleton Crater and Environmental Issues

- Due to depth, inside of crater receives no light (PSR)
- Rim of Shackleton Crater shown as point A is a peak of eternal light (PEL)
 - (89.68°S 166.0°W)
 - Longest Darkness Period (7 days)
 - Majority of lunar regolith dust accumulate around <5m above surface



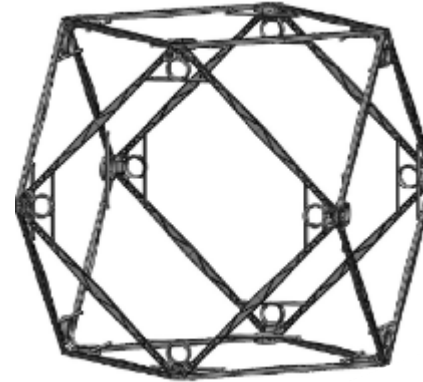
Requirement

***Requirements were developed based on environmental constraints and Viper Class Rovers**

| Requirement | Design Specification |
|-------------------------|--|
| Energy Storage Capacity | 80 kWh |
| Total Energy Generated | 260 kWh |
| Average Power Output | 481.48 W |
| Solar Tower Height | > 5m (\approx 16.4 ft) |
| Thermal Tolerance | System should function in (-232°C to +120°C) |

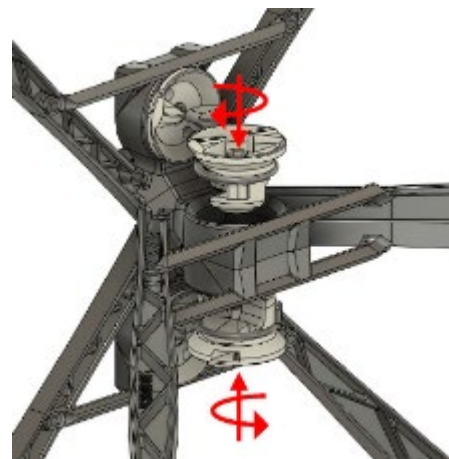
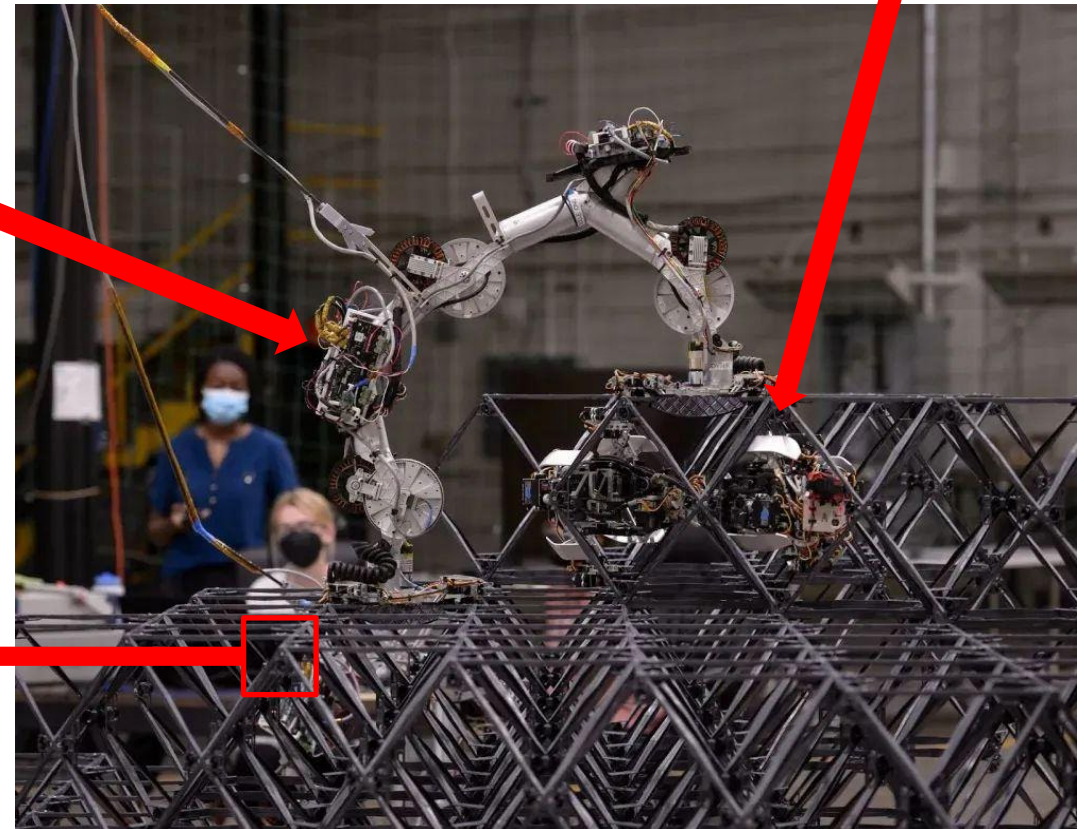
Building Block

- ARMADAS voxel
 - o Features
 - Cuboctahedron
 - Max length 12"
 - CF/plastic compound
 - Captive assembly
 - Different features proposed
 - o SOLL-E, MMIC-I

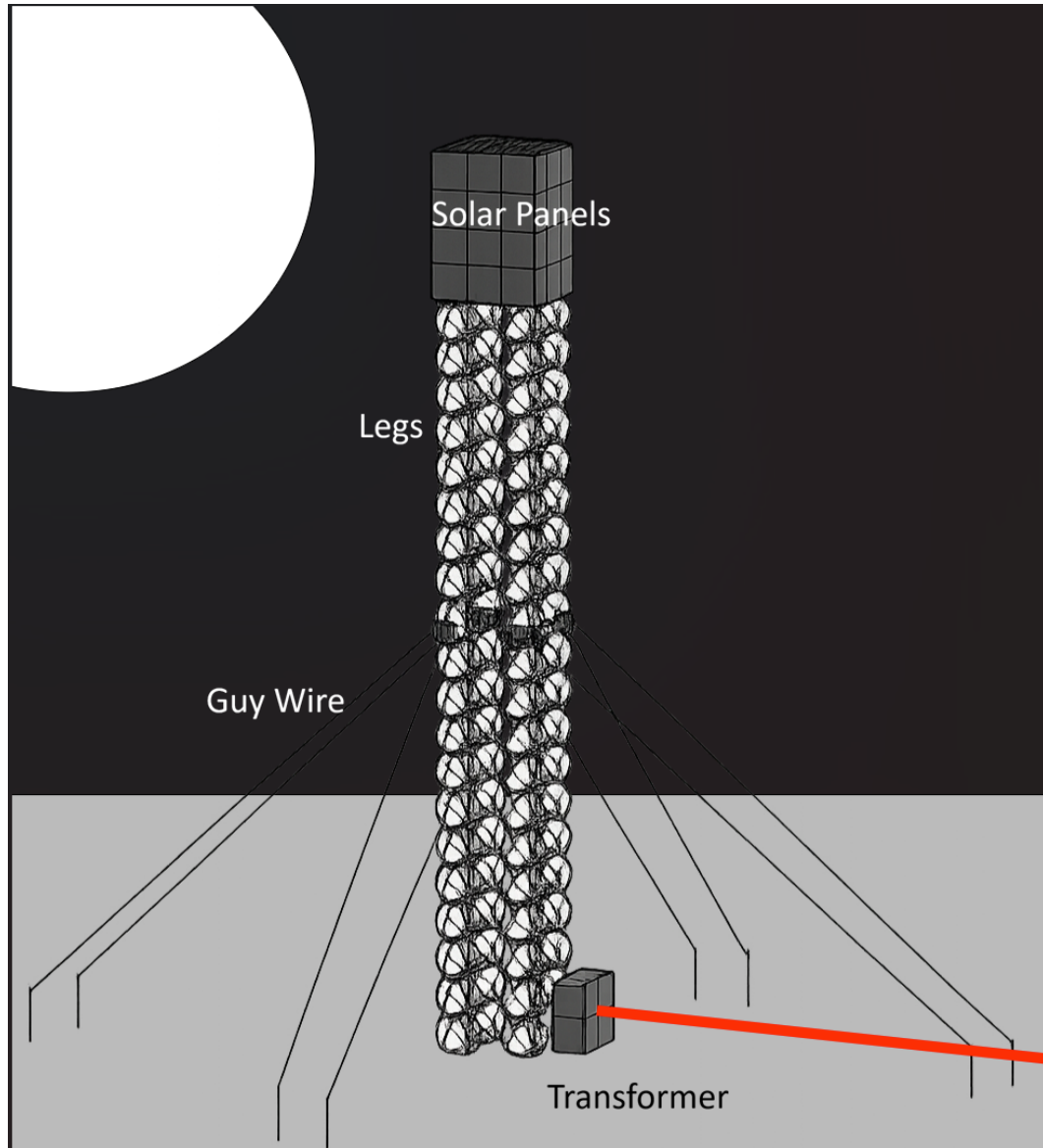


MMIC-I

SOLL-E

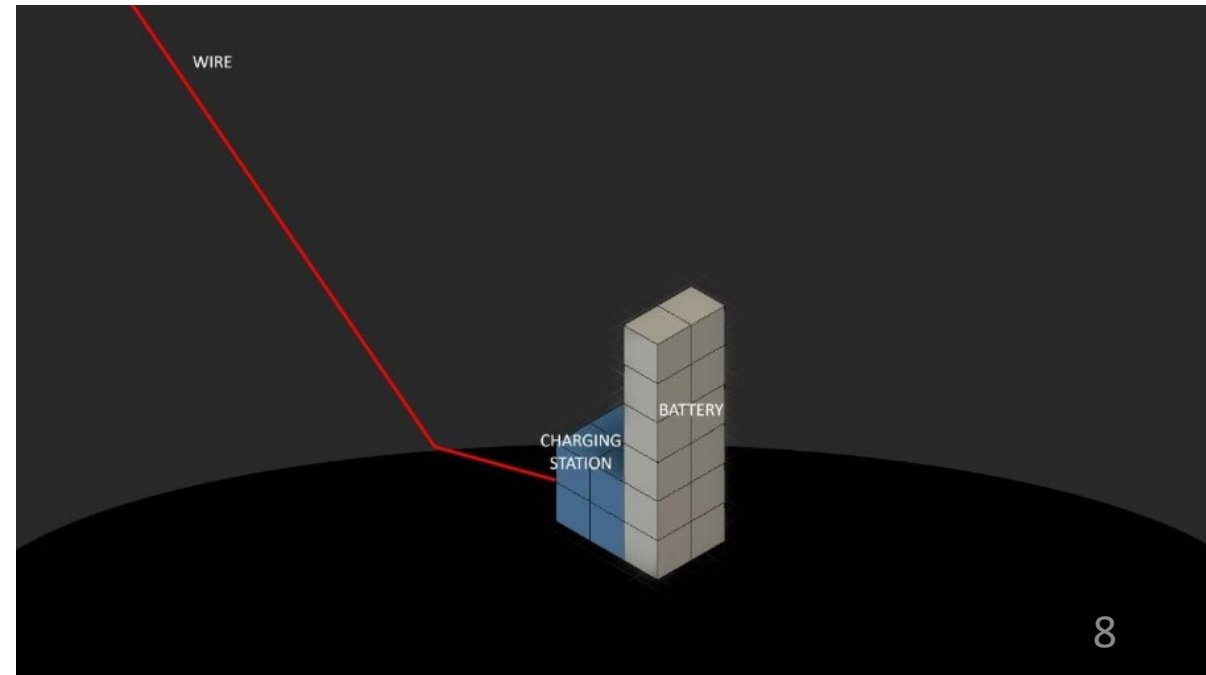


CAD Design

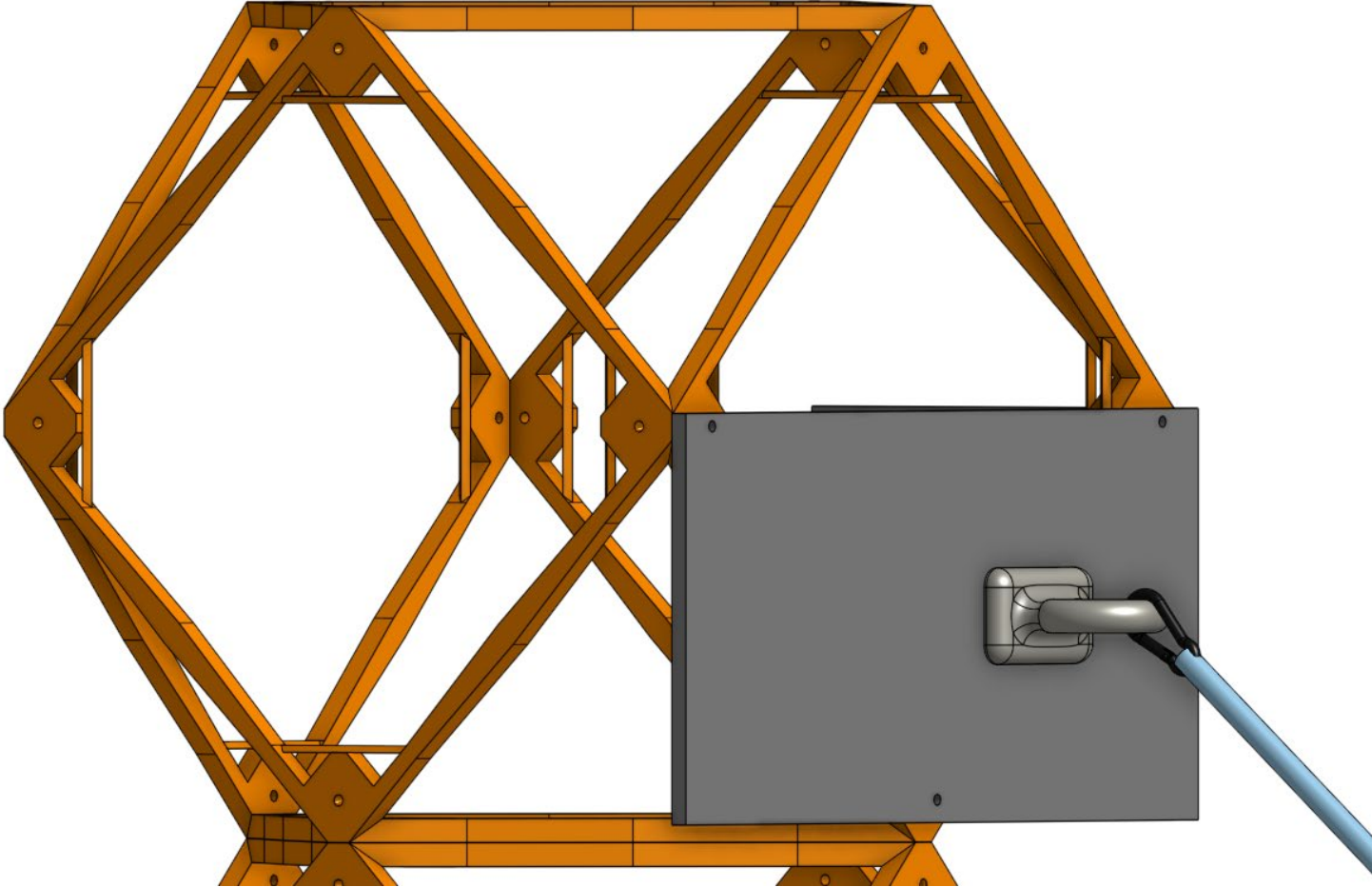


Solar Tower Specifications:

- 4 support legs, 20 ARMADAS voxels per leg
- Solar array: 48 panels total (4 sides × 12 panels)
- Top solar-panel support structure: 32 ARMADAS voxels
- Power cable length: 3.2 km
- Guy Wire length (each) = 4.4m



Guy Wire



Battery Storage Technology (Trade Study)

| Performance | Lithium Ion | Solid State Battery | Lithium Sulfur | Sodium Ion |
|--------------------------|--------------|--|----------------|--------------|
| Energy Density (Wh/kg) | 180 - 280 | 400 - 600 | 350 - 500 | 120 - 180 |
| Volume Density (Wh/L) | 350 - 550 | 400 - 800 | 350 - 700 | 250 - 400 |
| Life Cycle | ~ 5000 | 5000 - 10000 | 500 - 1000 | 1000 - 5000 |
| Round-trip efficiency | 90-95% | >90% (Some sources suggest up to 98%) | 85 - 95% | 90 - 95% |
| Operating Temp (Celsius) | -20 - +60 | -40 - +120 (could operate as low as -60) | -40 - +60 | -30 - +80 |
| Lifespan | 5 - 15 years | 10 - 20 years | 5 - 10 years | 5 - 15 years |

- Solid State Battery is best option for its high energy density, wide operating temperature range, and high life cycle



Power Generation and Panel Orientation (Trade Studies)

- *Evaluate Alternative Methods to Generate Power
- *Feasibility (1-10) Higher is better
- *Complexity (1-10) Lower is better

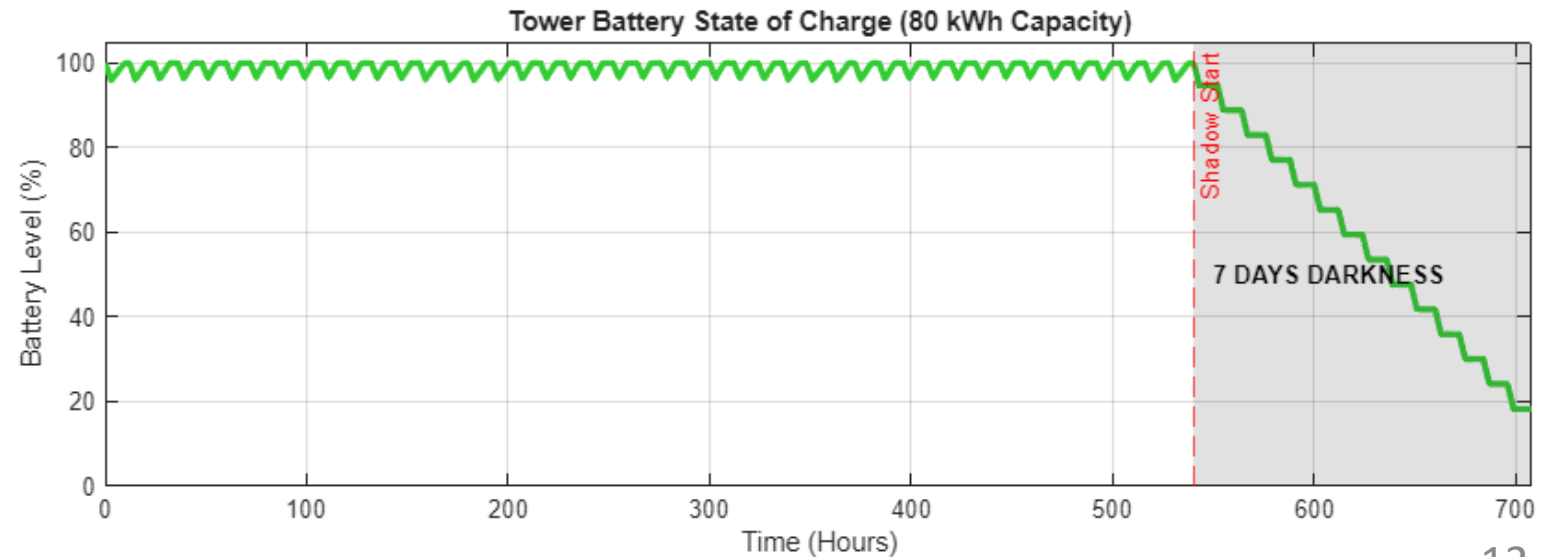
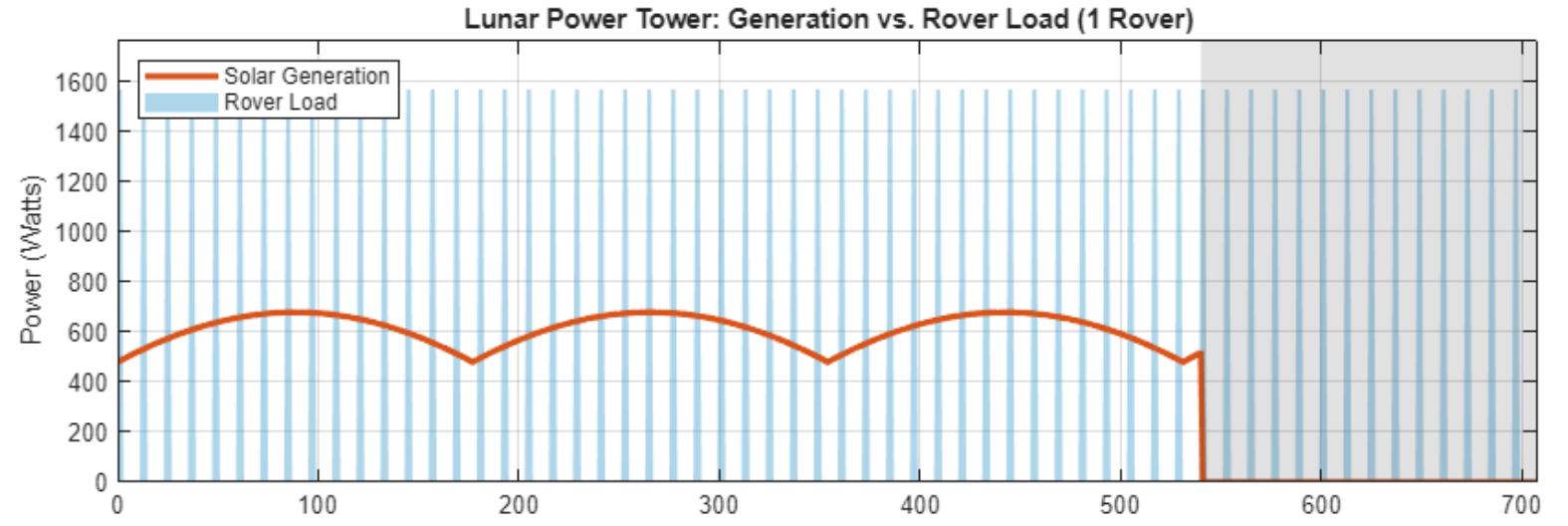
| Power Strategy | Feasibility | Complexity |
|---|-------------|------------|
| Option A: Static Reflective Facet Array | 1 | 2 |
| Option B: Panels on Rim + Transmission Line | 9 | 3 |
| Option C: Active Heliostat | 4 | 7 |
| Option D: Nuclear Fission Reactor | 6 | 10 |

| Design | Pyramid | Block (4 Faces) | Cylinder |
|---------------------|---------------------|---------------------|---------------------|
| Panel Tilt | 45 degrees | 88.5 degrees | 88.5 degrees |
| Power Factor | 0.725 | 1 | 1 |
| Required Panel Area | 6.02 m ² | 4.37 m ² | 3.44 m ² |
| Number of Voxels | 136 | 112 | 264 |
| Power Stability | Excellent | Excellent | Perfect |
| Assembly Complexity | 2 | 3 | 4 |

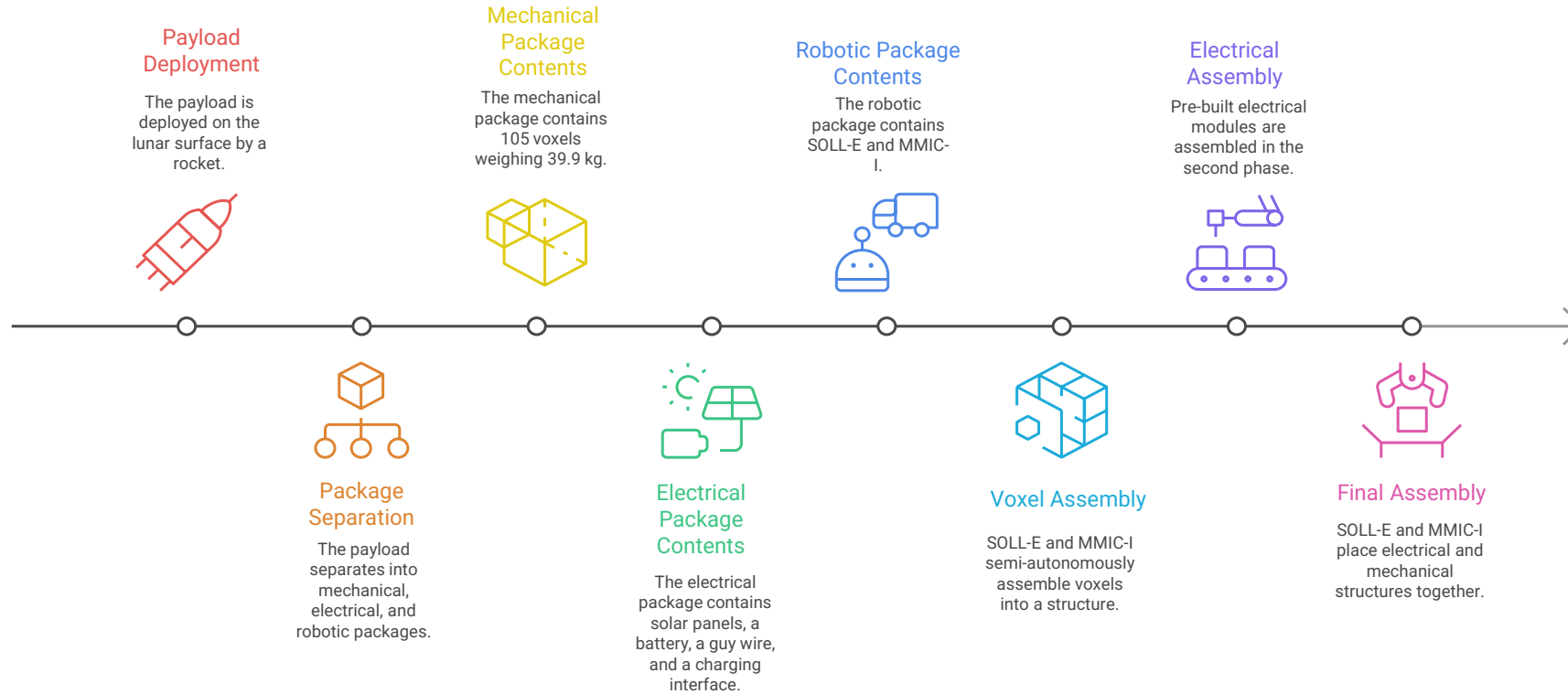


Power and Energy Performance

- During day charging, Battery is used as buffer to support load
- Darkness charging leaves battery SOC at ~19%

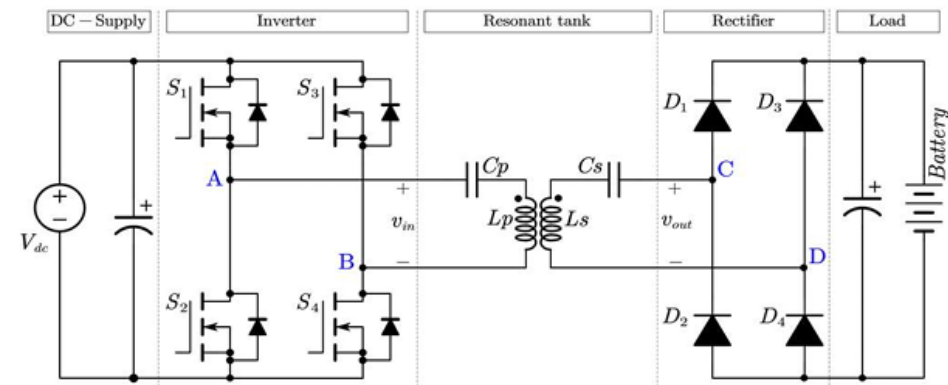
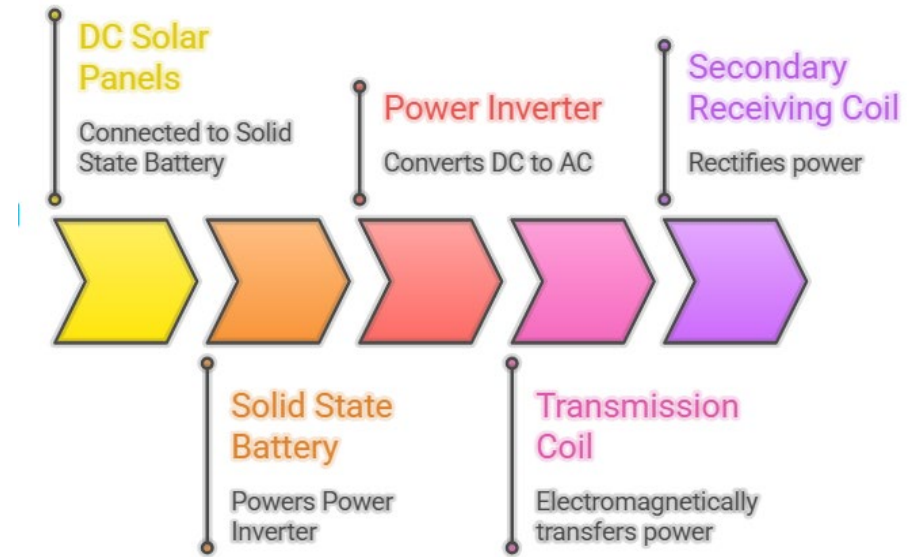


Lunar Payload Deployment and Assembly Sequence

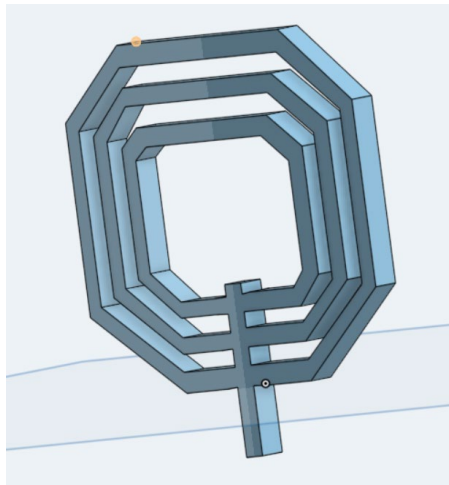
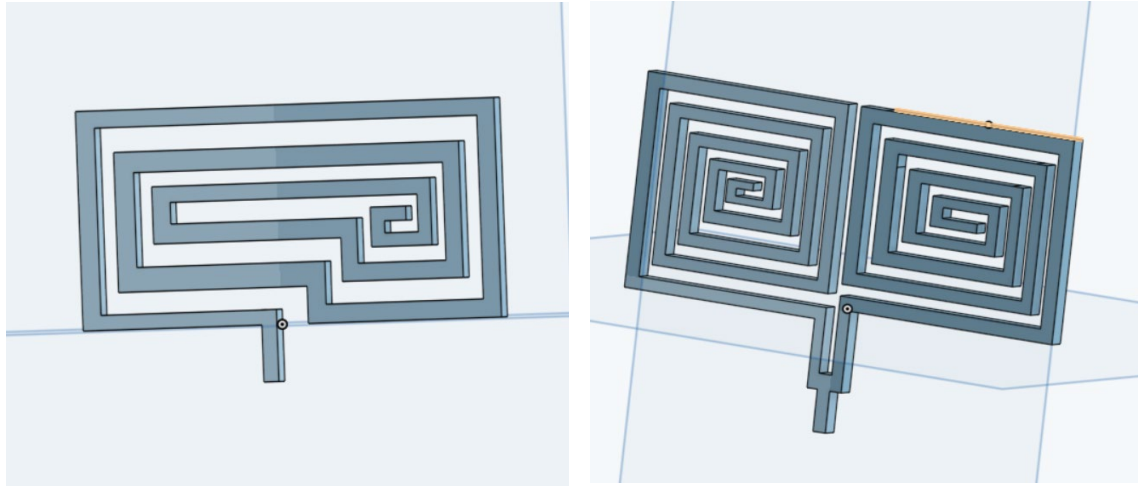


Second Phase – Electrical

- The electrical package will be unloaded from the payload where the solar panels, solid-state battery, and the inductive resonance charging interface will be ready to attach to the voxel structure.
- Our first pick for the solar panels will be the Z4J+ with 31% efficiency charging the solid state battery during the lunar light cycle.
- The electrical flow diagram would be represented as the solar panel connecting to the solid state battery ,then the solid state battery connecting to a inverter circuit.
- The power inverter circuit will convert DC power into AC power to setup the charging interface.



Charging Interface



- The charging interface could be reduced to three steps where the power inverter converts DC power to AC power after our AC power is transmitted through a custom coil design

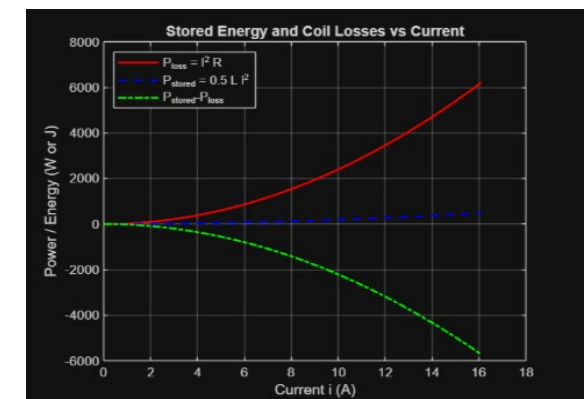
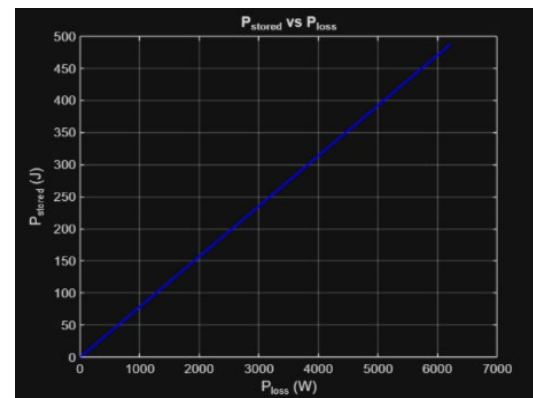
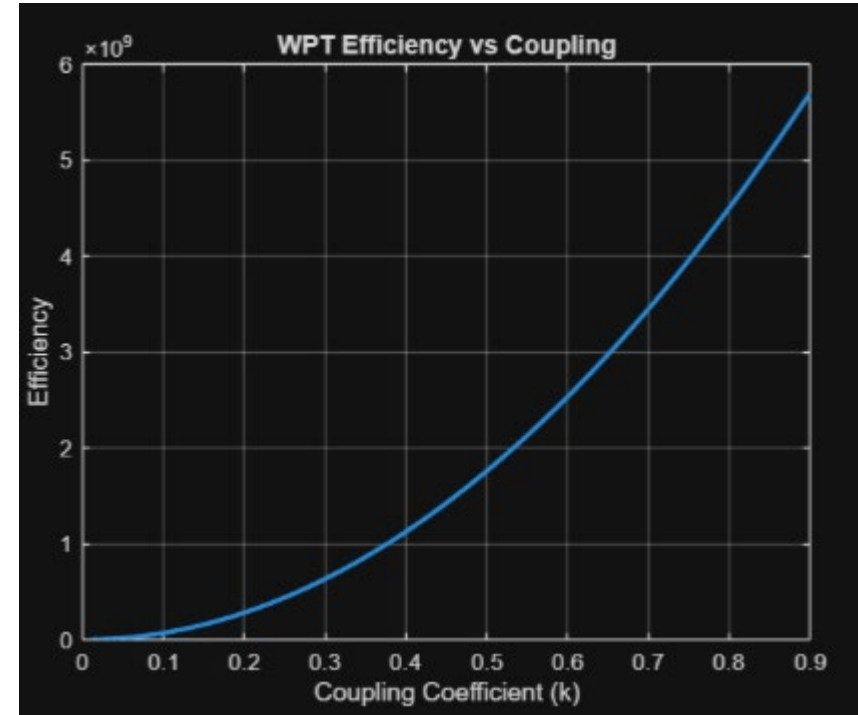
There are 3 coil designs each with different use cases depending on mission needs. There is Double Direction (DD), Double Direction Circle (DDC), and Hexagonal.

- Based on the materials of the coils it will determine the quality factor of the charging interface which is essential to storing power for the Rover.

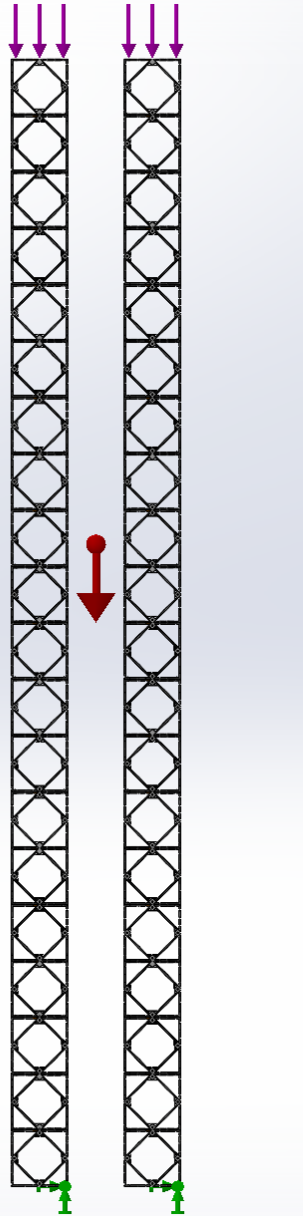
| Material Type | Sat Flux Density (T) | Initial Perm. | Frequency |
|----------------------|----------------------|------------------------------------|----------------|
| Mn-Zn Ferrite | 0.38 - 0.56 | $1 \times 10^3 - 1 \times 10^4$ | ~100kHz |
| Ni-Zn | 0.25-0.51 | $1 \times 10^2 - 2.3 \times 10^3$ | ~1 MHz |
| Ferrite | 0.20-0.51 | $.6 \times 10^2 - 1.3 \times 10^4$ | ~100kHz-2MHz |
| Litz-Copper | 0.01 | 1 | ~10MHz |
| Silver-Plated-Copper | 0.01 | 1 | ~20MHz |
| YBCO | 0.01 | 1 | ~10kHz-5 MHz |
| Magnetic Alloy | 1.2-1.3 | $8 \times 10^3 - 1 \times 10^5$ | ~1kHz - 500kHz |

Efficiency Curves

- From converting the power from DC to AC, designing the coil geometry, and carefully selecting coil materials for an efficient Q factor. Depending on the reactance and power dissipation we should see a model diagram as shown
- The curve displays the efficiency of the charger depending on the coupling (k)
- Along with the coupling (k) we model the losses and the power stored through a graph



Structure Analysis- Static



Assumptions

- Equal load sharing across 4 legs
- Bonded contacts used
- Guy wires excluded
- One-pillar simplification used for first-pass study

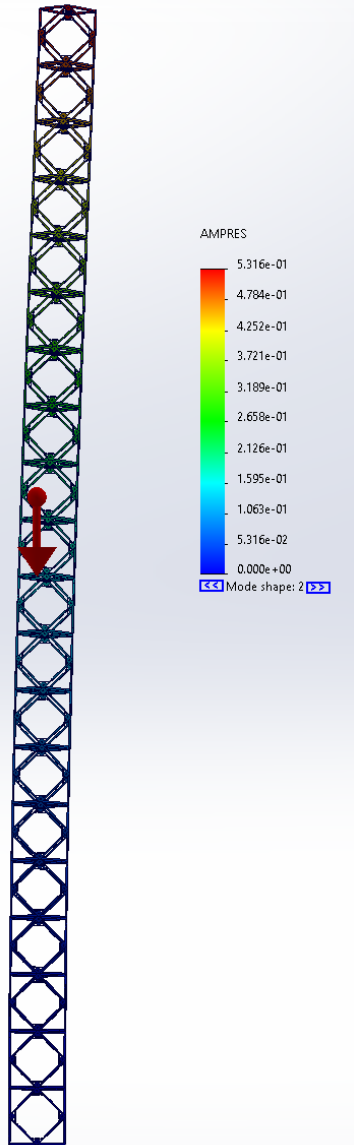
Conservative ARMADAS strength reference: 31.1 MPa

Static stress / strength ratio: $10.1 / 31.1 \approx 0.32$

- Maximum von Mises stress: 10.1 MPa
- Maximum resultant displacement: 4.73 mm
- Maximum equivalent strain: 4.41×10^{-4}
- Applied equivalent top load: 11.72 N per leg
- Gravity: 1.62 m/s^2 (lunar)

Takeaway: Static loading did not exceed the conservative ARMADAS strength limit. Instability and buckling are likely more critical than material crushing

Structure Analysis- Buckling



- The first buckling modes are dominated by lateral bending, indicating that guy-wire attachments would improve stability by bracing the tower against sideways deflection.
- Mode 1 critical load: $1.346334 \times 11.72 = 15.78 \text{ N}$
- Mode 2 critical load: $1.347506 \times 11.72 = 15.79 \text{ N}$
- Mode 3 critical load: $10.18472 \times 11.72 = 119.37 \text{ N}$
- Mode 4 critical load: $10.27703 \times 11.72 = 120.45 \text{ N}$

Takeaway: The support legs shows limited buckling margin, and the guy-wire would improve the tower stability.

Active Thermal Management

| Active Thermal Management Options | Purpose | Efficiency (COP, Energy consumption, and Practicality) | Complexity/Maintenance | Exclusion |
|--|-----------------------------|---|--|--|
| Electric Resistance Heaters | Heat Generation | High Performance Polymer | Simple unit with minimal maintenance | Selected: Highly efficient heat generator |
| Heat Pipes | Heat Transport | High | No moving parts, Tube routing, Tight physical contact | Selected: Can be used to prevent hotspots, transports heat effectively |
| Liquid Circulator | Bulk Heat Rejection/Cooling | High | Requires pumps, Valves, and a control system. Maintenance is moderate | Selected: Utilized to maintain stable temperatures and/or to remove bulk heat with other components to prevent overheating |
| Thermoelectric Coolers | Heating/Cooling | Very Low, Mass, Higher energy consumption | Introduces peltier elements, Pulse-Width Modulation controller, bi directional DC power, Ceramic substrates, and Semiconductors of P/N | Inefficient due to power drain, complex components and vulnerabilities |
| Active Louvers | Heat Rejection | Low | Actuators, moving blades, hinges, pivots. Anything that moves will need lubrication/greasing. | Best for huge amounts of heat that need to be expelled. Along with moving parts |
| Cryocoolers and Vapor-Compression Cycles | Cryogenic Cooling | High | Introduces noticeable vibrations, compressors, regenerator. Maintenance is expected to be high | Battery only needs to stay above -40C, it'll be overkill as a counteract to overheating. |
| Variable Emittance Radiators | Modulate Heat Rejection | Low radiation focus | Electronic control system, sensors, withstand temperature swings | Solely focused on radiation, overkill for that . Not enough to expel heat alone due to low radiation generation |

Utilizing Heat Pipes, Liquid Circulator, Electric Resistance Heaters due to their low energy cost and the ability to transfer heat, cool, and generate heat.



Automation - Overview

- Rationale
 - o ISRU enablement, role of astronauts
 - o Demonstrate automation by describing components and road to automation
- Design to usable data
- Telemetry
- Automation schemes

Figure 1: Some core concepts of automation

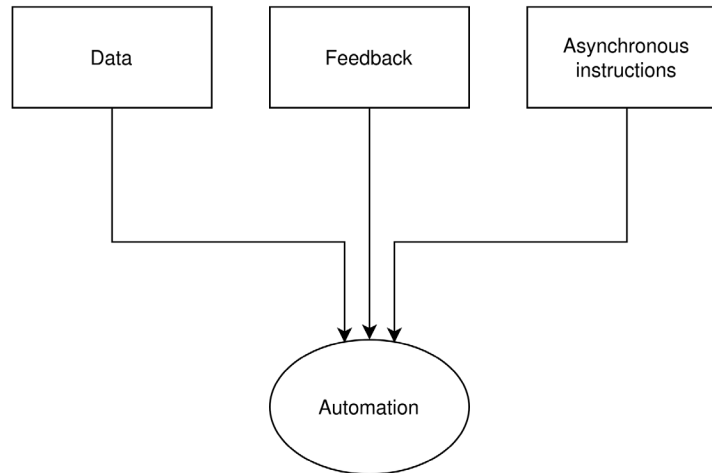
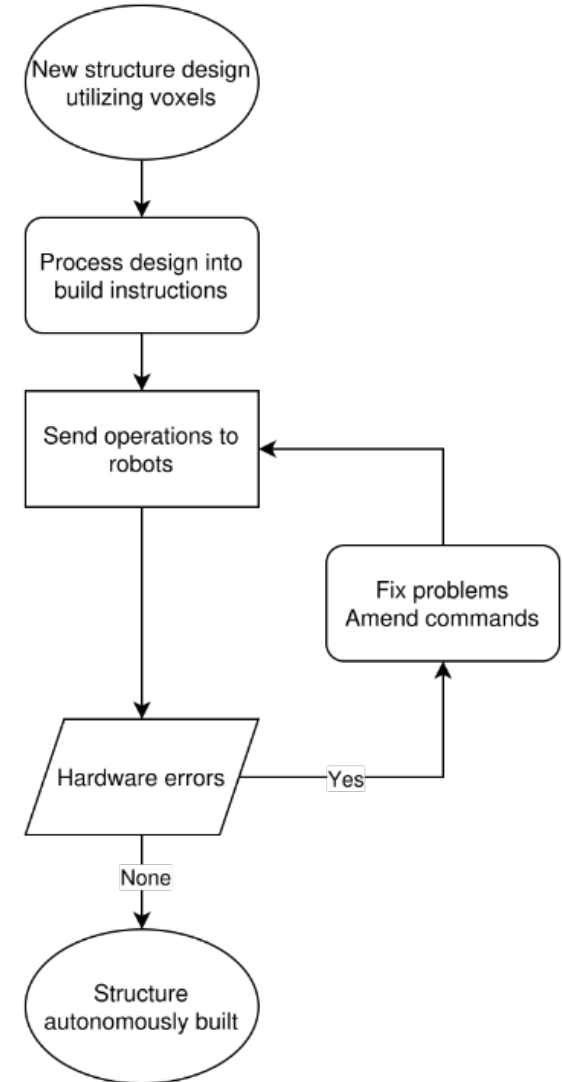


Figure 2: Simplified build process flowchart



Structure Design to Code

- Voxels as cartesian points
- Routing algorithms
 - o A*

Objective: Build speedups

Figure 1: Human-readable WKT and machine code WKT

POINT(2.0 4.0)

00000000014000000000000000004010000000000000

Figure 2: snippet of A* algorithm in pseudocode

```
while openSet is not empty
  current := the node in openSet having the lowest fScore[] value
  if current = goal
    return reconstruct_path(cameFrom, current)
  openSet.Remove(current)
  for each neighbor of current
    tentative_gScore := gScore[current] + d(current, neighbor)
    if tentative_gScore < gScore[neighbor]
// ...
```



Telemetry

- Wireless communication
- Moves via commands
- Component-level status reports

Figure 1: error conditions of SOLL-E

| Fault | Trigger |
|---------------------------------------|--|
| Stop robot | When the stop command is sent from the server |
| Gripper over current | When the current draw of gripper servo exceeds nominal operational level |
| Yaw motor over current | When the current draw of yaw DC motor exceeds nominal operational level |
| Yaw motor out of range | When the command value for yaw DC motor exceeds nominal operational value |
| Joint 1/2/3 motor response timeout | When the Joint 1/2/3 motor does not receive feedback from the external motor driver within the expected time frame |
| Joint 1/2/3 motor target mismatch | When the Joint 1/2/3 motor does not return the commanded target within the expected time frame |
| Joint 1/2/3 Absolute encoder mismatch | When the discrepancy between absolute joint and incremental shaft encoders for Joint 1/2/3 exceed an allowable threshold |
| Synchronization fault | When the board synchronization is indeterminate |

| | | | | | | |
|--------------------------|---------------------------|-----------------------|--------------------------|---------------------------|-----------------------|------------------------|
| 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| header | header | header | header | board number | lowByte hip-target | highByte hip-target |
| 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| lowByte hip-now | highByte hip-now | lowByte arm A-target | highByte arm A-target | lowByte arm A-now | highByte arm A-now | lowByte arm B-target |
| 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| highByte arm B-target | lowByte arm B-now | highByte arm B-now | lowByte gripper A-target | highByte gripper A-target | lowByte gripper A-now | highByte gripper A-now |
| 21 | 22 | 23 | 24 | 25 | 26 | 27 |
| lowByte gripper B-target | highByte gripper B-target | lowByte gripper B-now | highByte gripper B-now | lowByte V_{batA} | highByte V_{batA} | lowByte I_{batA} |
| 28 | 29 | 30 | 31 | 32 | 33 | 34 |
| highByte I_{batA} | lowByte I_{locA} | highByte I_{locA} | lowByte I_{gripA} | highByte I_{gripA} | lowByte I_{3v3A} | highByte I_{3v3A} |
| 35 | 36 | 37 | 38 | 39 | 40 | 41 |
| lowByte V_{regA} | highByte V_{regA} | lowByte I_{boA} | highByte I_{boA} | lowByte V_{batB} | highByte V_{batB} | lowByte I_{batB} |
| 42 | 43 | 44 | 45 | 46 | 47 | 48 |
| highByte I_{batB} | lowByte I_{locB} | highByte I_{locB} | lowByte I_{gripB} | highByte I_{gripB} | lowByte I_{3v3B} | highByte I_{3v3B} |
| 49 | 50 | 51 | 52 | 53 | 54 | 55 |
| lowByte V_{regB} | highByte V_{regB} | lowByte I_{boB} | highByte I_{boB} | target state | command complete | active bolter |
| 56 | 57 | 58 | 59 | 60 | 61 | 62 |
| bolter attempt | empty | empty | empty | fault byte0 | fault byte1 | fault byte2 |
| 63 | 64 | 65 | | | | |
| operating mode | lowByte checksum | highByte checksum | | | | |

Figure 2: MMIC-I's heartbeat data packet format

Automation

Pre-Operation:

- Parse design

Operation 1:

- Plan efficient routing
- Break down routing into system-level instructions
- Await interrupt from operation 2

Operation 2:

- Monitor physical status
- Send states to some telemetry sorter
- Send interrupt

Figure 1: S-E movement commands

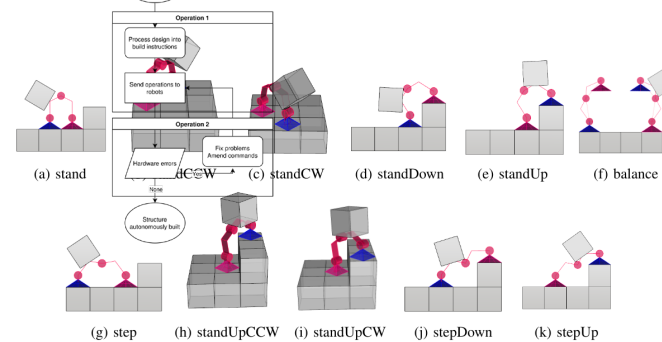
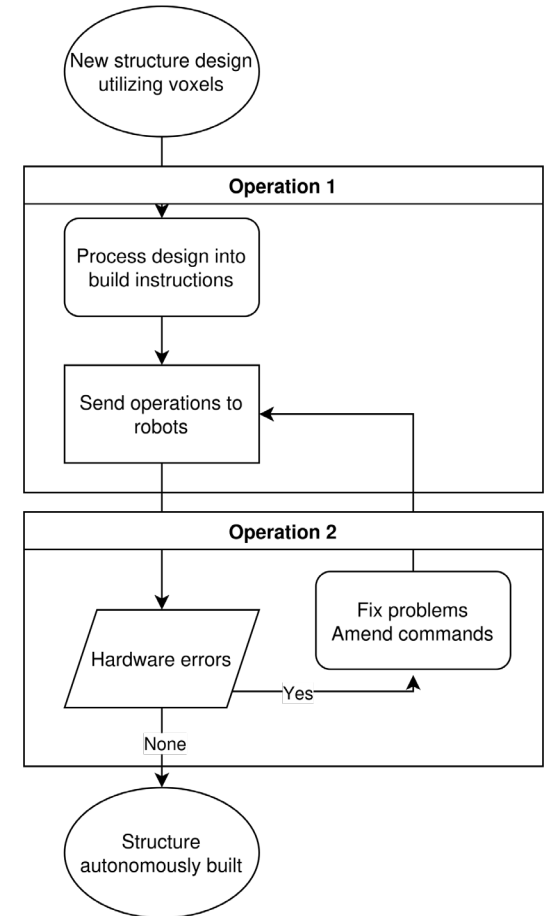


Figure 2: Threaded build process



A quick discussion on automation levels (trade study)

| | Fully autonomous | Semi-autonomous | Manual |
|-------------|---|--|--|
| Operator | Building agents | Some intermediary | By hand |
| Agency | The devices have full autonomy. | The devices do not have full autonomy but the system has full autonomy. | The devices are not autonomous. |
| Performance | Devices must have capacity to calculate and perform tasks. | Calculation and tasks can be delegated. | Performance is limited to operator. |
| Scaling | Each device must receive new firmware to communicate with new devices, offering more complicated scaling. | Intermediary can translate instructions of new devices to old devices, offering simpler scaling. | Ability to scale is limited to operator. |

Takeaway: semi-autonomous automation selected due to flexibility without losing too much automation.

Scaling

***For multiple rovers, split your power generation evenly between several towers for redundancy**

***Max tower height is to be capped at 60 ft**

2 Rovers:

- Double Battery Size, Double Solar Panel Area

3+ Rovers:

- Increase Battery Size by 80kwh for every additional rover
- # of Charging Station should be half of total rover count
- Increase Solar Panel Area by $\sim 1.11 \text{ m}^2$ for every additional rover

Summary/Challenge

- **Problem Addressed**
 - Extracting Lunar resources require energy
 - Short Operational and Mission time
 - No available light in Craters
 - Solar Panels Vulnerable to Dust Accumulation
- **Solution**
 - Generate and Store Energy for Wireless Charging
- **Challenge**
 - Robotic Assembler to connect Transmission Cable to Wireless Charger
 - Robotic Assembler to bolt Guy Wire into ground





Questions?

